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BULLETIN

OF THE

AMERICAN PHYSICAL SOCIETY

PROGRAMME OF THE

1954 WASHINGTON MEETING

AT

WASHINGTON, D. C.

April 29 and 30, and May 1, 1954

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BULLETIN

OF THE

AMERICAN PHYSICAL SOCIETY

1954 WASHINGTON MEETING, APRIL 29–30, MAY 1, 1954

THE **1954 Spring Meeting** of the American Physical Society will be held in Washington, D. C., on Thursday, Friday, and Saturday, **April 29 and 30 and May 1, 1954.** One gets weary of announcing year after year that the Washington Meeting will be larger than ever before; on this occasion the Secretary has not even counted the ten-minute papers, except far enough to assure himself that it would be necessary to have long sessions in order to avoid the use of halls too small for the expected audiences. Members with adding machines may ascertain whether the total surpasses the 387 of last year. The Secretary often apologizes for the occasional session of 16 papers; this time he feels more inclined to apologize for having made an occasional session reasonably short, thus emphasizing the lengthiness of the others. The sessions will be held in the Shoreham Hotel, the Sheraton Park Hotel (this is our old friend the Wardman Park under a new name), and the National Bureau of Standards. Hugh Odishaw, Chairman of our Local Committee of the past few years, has not recoiled before this heavy task: his Committee comprises also D. F. Bleil, W. C. Hull, R. D. Huntoon, C. K. Jen, R. J. Seeger, and Howard Tatel, thus including representatives of most of the Washington institutions that have to do with physics.

The hotels in which rooms were set aside for our members are the Shoreham and the Sheraton Park, and in addition the DuPont Plaza at DuPont Circle, the Roger Smith at 18th and Pennsylvania, the Willard at 14th and Pennsylvania, and the Windsor Park at 2300 Connecticut Avenue. If you have not already reserved your room, write at once to the hotel of your choice, mentioning that you are coming for the meeting of the Society. Willingness to share a room will make it easier to get one.

Registration desks will be set up in both the Shoreham and the Sheraton Park. All members and guests are asked to register and to **pay the modest registration fee** of one dollar. Our members will show a kindness to the overtaxed Local Committee by making their registrations in advance, wherever possible: send your name, the name of your hotel, and the dollar (which may be accompanied by payment for dinner tickets) to Mr. Hugh Odishaw, National Bureau of Standards, Washington 25, D. C. The bulletin boards carrying notices of messages and of the post-deadline papers will be set up in the Shoreham only, adjacent to the registration desks. Consult them frequently to see whether there are messages for you.

Invited papers on the general programme are fewer than last year, because the ten-minute papers are so numerous. The invited speakers are Cornelius Tobias, R. E. Zirkle, and Cyrus Levinthal in biophysics; D. E. Alburger, H. F. Kaiser, R. Sagane, Edward Teller, and G. M. Temmer in nuclear physics; R. P. Hudson, B. T. Matthias, and D. ter Haar in low-temperature physics; R. J. Rubin in statistical physics; Isabella Karle, Harry Jones, and R. L. Petritz in solid-state physics; Harold Lyons on the velocity of light; F. N. Frenkiel and Otto Laporte in fluid dynamics; and the speakers in the groups of papers which I next describe.

Our Division of Chemical Physics has arranged a **symposium on chemical applications of radio-frequency spectroscopy:** it is scheduled for Thursday morning; the speakers are N. F. Ramsey, H. S. Gutowsky, M. E. Packard, and C. H. Townes. For Friday morning is scheduled a group of **invited papers in electron physics** by L. Marton, David Pines, L. B. Loeb, and L. H. Fisher. To Saturday morning is assigned the **symposium on polarization of nucleons by scattering,** the speakers being Clyde Wiegand, John Marshall, John Tinlot, and Lincoln Wolfenstein.

Countless **ten-minute papers** are distributed among thirty-one sessions. Theoretical physics rambles through the whole of the meeting with six consecutive sessions: the theoretical brethren will become well acquainted with the Caribar Room in the Sheraton Park. Mesons, reactions of transmutation, neutrons, and radioactive nuclei continue to

flourish. Semiconductors, which will have enjoyed five sessions at the Michigan meeting, content themselves with half a session here. No topic which was assigned to Saturday afternoon at the 1953 Washington meeting will get it on this occasion. The Society owes gratitude to Robert Serber for arranging the papers in theoretical physics and to W. W. Havens for the like service to neutrons.

The **International Geophysical Year** (1957) will not be featured in our programme; but for the previous Wednesday afternoon (April 28) the National Academy of Sciences has arranged a programme under the title "Scientific Basis of the International Geophysical Year." The speakers will be Sidney Chapman, Henry Booker, A. B. Meinel, F. E. Roach, Carl Rossby, Harry Wexler, F. A. Whipple, D. H. Menzel, and L. R. Gould. The symposium will be held in the Building of the National Academy (2101 Constitution Avenue) from 2 to 5 in the afternoon. Our members are cordially invited.

The **banquet of the American Physical Society** will be held on Friday evening at seven in the Main Ballroom of the Shoreham Hotel. The after-dinner speakers will be E. R. Piore and P. Debye. The price of the dinner will be four dollars. Use the form on the inside back-cover page for advance reservation, and be reminded that you may include your check for the dinner with the registration fee if dispatched in advance to the Chairman of the Local Committee.

Tea will be served to members of the Society and their families at the Manse (on the grounds of the National Bureau of Standards) on Thursday afternoon between 4:30 and 6:30.

The **Nominating Committee** of the American Physical Society will meet on Friday at 4:30 P.M. in the Conference Room of the South Building of the National Bureau of Standards. This Committee consists of J. B. Platt (*Chairman*), E. U. Condon, H. L. Dryden, S. A. Goudsmit, M. H. Hebb, T. H. Johnson, A. O. Nier, W. K. H. Panofsky, and F. Seitz.

The **Council of the American Physical Society** will meet on **Thursday at 2:00 P.M.** in the Conference Room in the South Building of the National Bureau of Standards, unless contrary notice is distributed to its members.

The American Institute of Physics will operate a **Placement Service Register,** under the direction of Dr. Donald Kirkpatrick, at the Shoreham. Employers and applicants should report at the Register upon arrival at the meeting.

The American Institute of Physics will conduct an **exhibit of scientific books** at which publishers will show their latest texts. The exhibit will be located in the Shoreham near the registration desk.

The **Sigma Pi Sigma luncheon** will be held on Friday at 12:30 P.M. in the Sheraton Park. Tickets will be sold at the registration desk and may be reserved in advance by letter to Dr. Marsh W. White, Osmond Laboratory, Pennsylvania State University, State College, Pennsylvania.

Post-deadline ten-minute papers, pertaining to very recent achievements of very special importance, will be considered for admission to a special supplementary programme if the abstracts are received at the office of the Society not later than Friday, April 23. The abstracts will not be printed. The titles of such papers as may be accepted will be written on a blackboard near the registration desk at the Shoreham, and the papers will be given (under the usual ten-minute rule) at a special session in NBS, Materials and Testing, on Saturday afternoon beginning at 1:30.

Special programmes are being planned by the aides of the Local Committee for the **entertainment of the ladies,** including tours on Thursday and Friday afternoons and a luncheon on Friday. General information may be obtained at the special Ladies' Registration Desk to be set up in the foyer of the Shoreham. Mrs. Alan T. Waterman will be in charge of the Ladies' Programme.

Prospective meetings and deadlines of the Society are listed on page 6 of the Bulletin, together with instructions for the preparation of abstracts.

The abstracts printed in this Bulletin will reappear, exactly as they here stand, in an issue of *The Physical Review* after the meeting. Errata will be printed on a following page of *The Physical Review* if received not later than Monday, May 17, by Miss Ruth Bryans, American Institute of Physics, 57 East 55th street, New York 22, New York. Do not send in the abstract marked with corrections: write out the corrections in the form "Instead of . . . read. . . ." Add nothing.

KARL K. DARROW, *Secretary*
American Physical Society
Columbia University
New York 27, New York

Second Announcement of the 1954 Minneapolis Meeting

Details of this meeting were given in the March issue of this Bulletin. Deadline is Friday, April 30. Abstracts are to be sent to the address hereunder.

KARL K. DARROW, *Secretary*
American Physical Society
Columbia University
New York 27, New York

Second Announcement of the 1954 Seattle Meeting

Details of this meeting were given in the March issue of this Bulletin. Deadline is Wednesday, May 5. Abstracts are to be sent to the address hereunder. The following announcement is added.

The final day of the meetings, Saturday, July 10, will be at the Community House at Longmire in Mount Rainier National Park. In order to attend these meetings most people will want to spend the previous night in or adjacent to the Park. Reservations for accommodations at Longmire or Paradise Inn can be made by writing to the Mount Rainier National Park Company, Tacoma, Washington, specifying membership in the Society. Because the meeting occurs during the regular summer season at Mt. Rainier the Park Company is loath to hold accommodations open for very long. Hence it is imperative to make reservations as early as possible. Since accommodations at Longmire are limited, it will be best not to express a preference for Longmire or Paradise even if reservations are requested early. Those who fail to obtain reservations should write the Department of Physics in Seattle for reservations to be made locally at one of the Lodges just outside the Park entrance. The camp ground at Longmire will be open.

Mount Rainier National Park is 100 miles from Seattle. Visitors with cars will leave for the Park at various times Friday afternoon or evening, or, if desired, very early on Saturday morning. Bus transportation to the Park on Friday afternoon and for the 13-mile trip between Paradise Inn and Longmire on Saturday morning will be available for visitors without cars.

J. KAPLAN
Local Secretary for the Pacific Coast
University of California
Los Angeles 24, California

MEETINGS AND DEADLINES FOR THE REMAINDER OF 1954

I. Meetings east of the Rockies

Place	*Meeting dates*	*Deadline date*
Washington	April 29–30, May 1	Past
Minneapolis	June 28–30	April 30
Chicago	November 26–27	To be fixed

Abstracts of contributed papers for the foregoing meetings are to be sent to Karl K. Darrow, American Physical Society, Columbia University, New York 27, New York. To avoid danger of confusion, please do not send abstracts for any meetings until the deadline date of the previous meeting is past.

II. Meetings west of the Rockies

Seattle	July 7–10	May 5
Berkeley	December 26–31	To be fixed

Abstracts of contributed papers for these meetings are to be sent to J. Kaplan, University of California, Los Angeles 24, California.

RULES IMPOSED ON ABSTRACTS

The Council has ordered that abstracts shall be not longer than two hundred (200) words or the equivalent thereof. In reckoning equivalence, a footnote is equated to ten words; each line in a table to ten words; a "display" formula—one that requires a line to itself—is an expensive luxury equated to forty words.

Two copies of each abstract must be sent to the appropriate office. They must be typewritten and double spaced; one must be an original, the other may be an original or a carbon copy. Each abstract must be confined to a single page: if it is too long for a single page it is too long to be printed. Write each abstract as a single paragraph: the suppression of paragraphs costs time and labor to the editors. Look at the abstracts in this *Bulletin* to see how the title of the paper and the name of the author are to be arranged and follow the example. Issues of the *Bulletin* are sometimes appreciably delayed because the editors have to do what the authors should have done.

Remember the rule of the Council that, if an author submits more than one abstract, all but one must go onto the Supplementary Programme. In enforcing this rule, an abstract is credited to the author whose name appears first in the by-line.

The use of special delivery is perilous. For reasons which we do not pretend to understand, special-delivery stamps sometimes produce the inverse of the effect expected. Telegraphed abstracts will no longer be accepted.

EPITOME OF THE 1954 WASHINGTON MEETING

(Personal names are those of invited speakers. NBS stands for National Bureau of Standards, SP for Sheraton Park.)

Thursday Morning

A. Chemical applications of radio-frequency spectroscopy: Ramsey, Gutowsky, Packard, Townes; Business Meeting of Division of Chemical Physics. Shoreham, Main Ballroom.
B. Nonmetallic solids, I (including semiconductors). SP, Continental Room.
C. Apparatus of nuclear physics, I. Shoreham, West Ballroom.
D. Low-temperature physics. SP, Burgundy Room.
DA. Theoretical physics, I (nuclear theory). SP, Caribar Room.
E. Tobias, Zirkle, Levinthal. NBS, East Building.

Thursday Afternoon

F. Jones: magnetic resonance and allied topics. Shoreham, West Ballroom.
FA. Apparatus of nuclear physics, II; other topics in nuclear physics. Shoreham, Main Ballroom.
G. Radioactive nuclei, I. SP, Continental Room.
H. Chemical and general physics. NBS, East Building.
I. Nonmetallic solids. II. SP, Burgundy Room.
IA. Theoretical physics, II (high-energy scattering). SP, Caribar Room.

Friday Morning

J. Marton, Pines, Loeb, Fisher. NBS, East Building.
JA. Spectra from x-rays through microwaves. SP, Burgundy Room.
K. Meson scattering; meson absorption; mesonic atoms. Shoreham, West Ballroom.
KA. Radioactive nuclei, II. SP, Continental Room.
L. Temmer; electric excitation of nuclei; photonuclear reactions. Shoreham, Main Ballroom.
M. Theoretical physics, III (field theory). SP, Caribar Room.

Friday Afternoon

N. Alburger, Kaiser, Teller. Shoreham, Main Ballroom.
O. Lyons, Karle, ter Haar, Matthias, Hudson. NBS, East Building.
OA. Electrostatic and electron physics. NBS, Materials and Testing.
P. Neutron physics, I (neutron scattering). SP, Continental Room.
PA. Meson production. Shoreham, West Ballroom.
Q. Reactions of transmutation. I. SP, Burgundy Room.
QA. Rubin; theoretical physics, IV (statistical mechanics). SP, Caribar Room.

Friday Evening

Banquet of the American Physical Society; Piore, Debye. Shoreham, Main Ballroom.

Saturday Morning

R. Polarization of nucleons by scattering: Wiegand, Marshall, Tinlot, Wolfenstein. Shoreham, Main Ballroom.
RA. Neutron physics, II (neutron resonances). SP, Continental Room.
S. Cosmic rays. Shoreham, West Ballroom.
SA. Reactions of transmutation, II. SP, Burgundy Room.
T. Magnetism. NBS, East Building.
U. Theoretical physics, V (field theory and interactions). SP, Caribar Room.

Saturday Afternoon

V. Theoretical physics, VI (atoms and electrons). SP, Caribar Room.
VA. Frenkiel, Laporte; fluid dynamics. SP, Burgundy Room.
W. Neutron physics, III. SP, Continental Room.
X. Sagane; Strange particles of the cosmic rays. Shoreham, Main Ballroom.
Y. Nucleonic scattering. Shoreham, West Ballroom.
Z. Petritz; solid-state physics, III, mostly metals. NBS, East Building.
ZA. Post-deadline papers, if any. NBS, Materials and Testing.

PROGRAMME

THURSDAY MORNING AT 10:00

Shoreham, Main Ballroom

(BRYCE CRAWFORD, JR., presiding)

Symposium of the Division of Chemical Physics

Chemical Applications of Radio-Frequency Spectroscopy

A1. Molecular-Beam Studies of Molecules. N. F. RAMSEY, *Harvard University.* (35 min.)

A2. Structural Determinations by Nuclear Magnetism. H. S. GUTOWSKY, *University of Illinois.* (35 min.)

A3. Chemical Applications of Nuclear Magnetic Resonance. M. E. PACKARD, *Varian Associates.* (35 min.)

A4. Recent Applications of Microwave Spectroscopy to the Study of Molecules. C. H. TOWNES, *Columbia University.* (35 min.)

Business Meeting of the Division of Chemical Physics

(To be convoked during Session A whenever the Chairman shall see fit.)

THURSDAY MORNING AT 10:00

Sheraton Park, Continental Room

(DAVID PINES presiding)

Nonmetallic Solids, I (Including Semiconductors)

B1. Thermal Conductivity of Semiconductors. A. NEAVES AND D. TER HAAR,* *St. Andrews University, Scotland.*—Using methods due to Wilson[1] and Makinson[2] we have evaluated the electronic thermal conductivity K_e and the lattice thermal conductivity K_g for the case of semiconductors, when to a first approximation we can use a Maxwell distribution for the conduction electrons. As far as K_g is concerned, Sommerfeld and Bethe[3] have shown that the main contribution arises from the changed lattice distribution function, if we are dealing with metals. In the case of semiconductors the change in the electron distribution function is, however, important.

* On leave of absence at Purdue University.
[1] A. H. Wilson, Proc. Cambridge Phil. Soc. **37**, 371 (1937).
[2] R. E. B. Makinson, Proc. Cambridge Phil. Soc. **38**, 474 (1938).
[3] A. Sommerfeld and H. Bethe, Handbuch der Physik **242**, 333 (1933).

B2. Electronic Thermal Conduction in Semiconductors. P. J. PRICE, *Watson Laboratory.*—A temperature gradient in a semiconductor leads to gradients of the carrier concentrations, and hence to carrier diffusion currents

$$\mathbf{N}_1=\mathbf{N}_2=-\frac{\sigma_1\sigma_2}{\sigma_1+\sigma_2}\left(\frac{k}{e}\right)^2\left[\frac{\Delta}{kT}+3+\gamma_1+\gamma_2\right]\text{grad}T, \qquad (1)$$

where Δ is the energy gap between the bands, and the (thermal diffusion) factors γ_1 and γ_2 are each $\frac{1}{2}$ for pure lattice scattering. (We have assumed nondegeneracy in the electron and hole distributions, and neglected any "impurity band" transport effects.) Each electron-hole pair transports annihilation energy Δ, as well as band energy of order kT; and hence the carrier flow contributes, to the thermal conduction

$$K_{\text{flow}}=\frac{\sigma_1\sigma_2}{\sigma_1+\sigma_2}\left(\frac{k}{e}\right)^2\left[\frac{\Delta^2}{kT}+\alpha\Delta+\beta kT\right], \qquad (2)$$

where α and β again depend on the scattering processes. For silicon and germanium, the term in Δ^2 of (2) could attain about 0.3 watt units at their melting points. There is thus the possibility of minima, at high temperatures, in the total thermal conductivities.

B3. Comparison of Hall and Magnetoresistance Phenomena in InSb with those in Germanium.* T. C. HARMAN, R. K. WILLARDSON, AND A. C. BEER, *Battelle Memorial Institute.*—Studies of Hall coefficients and resistivities as functions of temperature and of magnetic field reveal interesting differences in the behavior of p-type InSb[1] and p-type germanium.[2] The effects in InSb are adequately explained by an extension of Harding's work to include arbitrary concentrations of both p- and n-type carriers. The shift in temperature of the Hall coefficient crossover, the Hall coefficient maximum, and the magnetoresistance maximum with magnetic field can be predicted. No maxima in magnetoresistance *versus* temperature were observed in high-purity p-type germanium (80°K to 600°K). Furthermore, the shift of the Hall coefficient crossover temperature with magnetic field in germanium is in the opposite direction from that in InSb; a behavior at variance with predictions from the two-carrier model. Experimental values of $\Delta R/R_0$ and $\Delta\rho/\rho_0$ are shown as functions of temperature for InSb and germanium. Results are compared with calculated values given in terms of an implicit temperature parameter $n_1\mu_1/n_2\mu_2$.

* Supported in part by the Wright Air Development Center.
[1] Willardson, Beer, and Middleton, Phys. Rev. **93**, 912(A) (1954); O. Madelung, Z. Naturforschr. **8a**, 791 (1953).
[2] W. C. Dunlap, Phys. Rev. **71**, 471 (1947); **79**, 286 (1950); **82**, 329 (1951).

B4. Application of a Three-Carrier Model to the Hall Effect in Germanium. R. K. WILLARDSON, T. C. HARMAN, AND A. C. BEER, *Battelle Memorial Institute.*—Recent cyclotron resonance observations[1] on p-type germanium at 4°K have indicated the existence of positive holes with effective masses of 0.04m and 0.30m. An appreciable difference in mobility of these two p-type carriers may therefore be expected. In fact, the mobility of the holes of lower effective mass should be significantly greater than that of the electrons ($m^*=0.11$m). The presence of this additional p-type carrier of high mobility can explain why the Hall coefficient changes with increasing magnetic field from positive to negative in the neighborhood of the crossover point. Furthermore, the unusually large changes in extrinsic Hall coefficient with magnetic field are explained. In particular, the rapid decrease with increasing magnetic field of the Hall coefficient at 80°K for fields below 1000 gauss[2] is accounted for. Initial calculations indicate a reasonably good fit of experimental data is obtained by taking the mobility of the holes with the lower effective mass to be about five times that of the ordinary hole mobility. The contribution of these carriers is about 20 percent of the observed p-type conductivity.

[1] Dresselhaus, Kip, and Kittel, Phys. Rev. **92**, 827 (1953).
[2] Harman, Willardson, and Beer, "Note on Hall coefficient in germanium," submitted for publication as a letter to the editor of Phys. Rev.

B5. Radioactive and Photoelectric $p-n$ Junction Power Sources. W. G. PFANN AND W. VAN ROOSBROECK, *Bell Telephone Laboratories.*—An electrical power source can be made by bombarding a $p-n$ junction with beta particles so that electron-hole pairs produced by radiation are separated by the junction field.[1] Such radioactive cells have been constructed; equations for maximum output power W and efficiency F, applicable to photocells also, have been derived; and a detailed study of the factors which limit W and F has been completed. F increases with the source-current I_g of separated charges and with the zero-voltage junction resistance R_0. While I_g increases with amount and activity of the isotope and energy of its radiation, it is limited by self-absorption in the isotope and the need for keeping beta energies below the threshold for formation of lattice defects in the semiconductor. These factors materially limit W and F for $Sr^{90}-Y^{90}$ cells. Of germanium and silicon cells made with $Sr^{90}-Y^{90}$, cell currents were higher for germanium, because of longer diffusion lengths and shorter beta range; but cell powers were higher for silicon, because of larger R_0. Operating at −10°C increased the power of a germanium cell by a factor of 24.

[1] P. Rappaport, Phys. Rev. **93**, 246 (1954).

B6. Some Electrical Properties of Several Silicon-Germanium Alloys.* L. DAVIS, JR., G. A. DEMARS, L. G. RUBIN, AND W. D. STRAUB, *Ratheon.*—Large crystallites of Si−Ge alloys ranging in composition from 14 percent to 84 percent Ge were obtained from melts that were cooled from above the solidus to below the liquidus at the rate of 2°C per hour. The lattice constants of several samples were determined from density measurements and powder patterns and checked the values of Stor and Klemm[1] within 0.1 percent. The x-ray line widths indicated a spread of 2 percent to 16 percent in sample compositions, the larger spreads coming in the high Ge content samples. Measurements of intrinsic resistivity *versus* temperature resulted in energy gap values of $E_G=1.13$ ev for the compositional range 14 percent–50 percent Ge and $E_G=1.02$ ev for 62 percent–84 percent Ge. All samples were p type with Hall hole mobilities of about 550 cm²/volt sec for the 62 percent–74 percent Ge range and about 250 for the 14 percent–34 percent Ge range. In general, the measurements were performed on single crystal samples.

* Work supported in part by U. S. Bureau of Ships, Air Corps, and Signal Corps.
[1] H. Stor and W. Klemm, Z. anorg. Chem. **241**, 305.

B7. Anisotropy of Cyclotron Resonance in Germanium.* Part I Theory. BENJAMIN LAX, H. J. ZEIGER, AND R. N. DEXTER, *Lincoln Laboratory.*—Calculations by Shockley,[1] Herman, and others[2] on the band structure of germanium suggested that the energy surfaces for the conduction band in k space might consist of six ellipsoids of revolution with principal axes along the [100] directions. Experimental results on cyclotron resonance in n-type germanium at microwave frequencies and liquid helium temperatures indicate that the surfaces are eight ellipsoids of revolution with principal axes along the [111] directions. Based on this model, equations of motion for electrons in the conduction band are written in terms of a longitudinal mass m_1 and a transverse mass m_2. Expressions are obtained for the effective mass for an arbitrary orientation of dc magnetic field with respect to the crystalline axis. These allow the determination of m_1 and m_2 from the positions of the magnetic resonance peaks. Theoretical expressions are developed for the rf absorption as a function of dc magnetic field, for arbitrary orientation of magnetic field and rf electric field with respect to the crystalline axes. From the resonance line shapes, the relaxation time for scattering of conduction band electrons can be estimated.

* The research reported in this document was supported jointly by the Army, Navy, and Air Force under contract with the Massachusetts Institute of Technology.
[1] W. Shockley, Phys. Rev. **90**, 491 (1953).
[2] F. Herman, Phys. Rev. **88**, 1210 (1952); F. Herman and J. Callaway, Phys. Rev. **89**, 518 (1953).

B8. Anisotropy of Cyclotron Resonance in Germanium.* Part II Experiment. R. N. DEXTER, H. J. ZEIGER, BENJAMIN LAX, AND E. S. ROSENBLUM, *Lincoln Laboratory.*—Experiments have been performed on cyclotron resonance in ~40 ohm-cm p-type and n-type single crystals of germanium. Measurements were made at liquid helium temperatures at microwave frequencies of 8895 Mc per second and 23 650 Mc per second. The germanium sample was mounted in a rectangular cavity, and the power absorbed in the cavity was detected by a recording spectrometer. Observations were made as a function of dc magnetic field for various orientations of the magnetic field in the (110) plane. At an rf electric field of about ~4 volts/cm in the sample "breakdown" was observed. A relaxation oscillation, associated with "breakdown" and "quenching," appeared at this critical field. For cyclotron resonance the electric field in the sample was maintained at ~0.1 volt/cm, well below the "breakdown" field. P-type germanium resonance showed no directional anisotropy and the results were in agreement with those previously reported.[1] The n-type germanium resonance curves showed distinct anisotropy effects. Good agreement between theory and experiment was obtained for values of longitudinal mass $m_1=1.3\ m_0$ and transverse mass $m_2=0.08\ m_0$.

* The research in this document was supported by the Army, Navy, and Air Force under contract with the Massachusetts Institute of Technology.
[1] Dresselhaus, Kip, and Kittel, Phys. Rev. **92**, 827 (1953).

B9. A. C. Photoconductivity in Phosphors.* J. J. DROPKIN AND S. ORGEL,† *Polytechnic Institute of Brooklyn.*—An ac method has been used to determine the resistance and capacitance of a number of phosphors under uv and ir irradiation for the frequency range 20 to 100 cps. The phosphor R and C decrease with increasing frequency. The behavior of both R and C are accurately described by a Debye dispersion equation of the type given by Koops[1] for grain conduction. (Other mechanisms give the same equations.) The asymptotic value of the resistance for increasing frequency is proportional to the interelectrode distance, inversely proportional to the square root of uv intensity, and inversely proportional to the ir intensity. The kinetics of photoconduction in phosphors indicate that the asymptotic resistance can therefore be used as a measure of the photoresistance of the phosphor.

* Supported in part by the U. S. Office of Naval Research.
† Present address: 102 Court F, West Lafayette, Indiana.
[1] C. G. Koops, Phys. Rev. **83**, 121 (1951).

B10. X-Ray Production of F Centers in NaCl and LiF.* R. C. HERMAN, L. L. MADOR,† R. F. WALLIS, AND M. C. WILLIAMS, *Applied Physics Laboratory, The Johns Hopkins University.*—The relative energy loss of a heterogeneous x-ray beam has been calculated as a function of depth of penetration in NaCl and LiF crystals, and compared with curves of *F*-center absorption obtained by scanning in depth, perpendicular to the x-ray beam, crystals x-rayed for various times at 30 or 50 kv. It is found that *F*-center production in NaCl is proportional to the energy loss for short x-ray exposures. For longer exposures *F*-center production efficiency decreases, although no saturation has yet been obtained. After 24-hour exposures an anomalous increase in production is observed near the x-rayed face. On the other hand, for LiF the *F*-center production efficiency is almost constant, and the absorption-depth curves fall off more steeply than the calculated energy loss curves. This discrepancy might result from luminescence effects which are more pronounced than in NaCl, or might indicate a difference in mechanism for the production of *F* centers in LiF. The technique for measuring, perpendicular to the direction of the x-ray beam, the absorption of essentially homogeneous *F*-center concentrations is useful for the quantitative study of growth and decay effects.

* This work was supported by the Bureau of Ordnance, Department of the Navy.
† Now at Research Division, National Distillers Products Corporation, Cincinnati, Ohio.

B11. Effects of Preparation and Temperature on the Response of NaI Phosphors.* C. O. MUEHLHAUSE, E. DER MATEOSIAN, AND MICHAEL MCKEOWN, *Brookhaven National Laboratory.*—Phosphors of NaI with and without Tl were grown both by the method of Bridgman and of Kyropoulos.[1] Pulse height *vs* temperature curves were measured for both alpha particles and electrons in the temperature range from 77°K to 300°K. These data were taken with a Dumont 6292 photomultiplier and an 0.8 μs rise time linear amplifier having an input integrating time of $\sim$20 μs. It was found that the ratio of the pulse height per unit energy of the alpha particle to that of the electron was dependent on both the method of preparing the phosphor and on the temperature of its operation. In some cases, this ratio was observed to be greater than unity. The data also suggested that the effects of Tl activation are important at temperatures above $\sim$175°K. At temperatures below $\sim$160°K luminescent centers other than those due to Tl play an important role. Phosphors that were grown too rapidly exhibited an anomalous resolution which was not a monotonic function of the temperature. At temperatures below $\sim$100°K faster fluorescent components were observed than have been reported previously.[2]

* Research performed under the auspices of the U. S. Atomic Energy Commission.
[1] S. Kyropoulos, Z. anorg. u. allgem. Chem. **154**, 308 (1926).
[2] J. Bonanomi, J. Rossel, Helv. Phys. Acta **24**, 310 (1951). J. Bonanomi, Helv. Phys. Acta **25**, 725 (1952).

B12. Ionic Conductivity and X-Ray Coloration of Alkali Halides. F. A. CUNNELL AND E. E. SCHNEIDER,* *University of Durham, England.*—Extensive investigations of the structure sensitive ionic conductivity down to 100°C of pure crystals of LiF, NaCl, KCl, KBr, KI, and crystals of KCl−Sr and NaCl−Mn have been carried out with a dc method allowing the direct observation of polarization effects on a CRO. The experiments have revealed consistent deviations from a linear $\log\sigma - 1/T$ relation and a significant lowering of the conductivity following either heat treatment (quenching) or x-ray coloration of the crystals. These results and those on the magnitude and duration of the polarization have been interpreted in terms of an effective block structure of single crystals resulting from a nonuniform distribution of imperfections. Experiments on the correlation between ionic conductivity and darkenability by x-rays, as affected by heat treatment and divalent impurity content, have lent further support to these ideas.

* 1953–54 at Duke University, Durham, North Carolina.

B13. Thermal Restoration of Color Centers at Low Temperature. R. V. HESKETH AND E. E. SCHNEIDER,* *University of Durham, England.*—X-ray colored crystals of KCl can be partially bleached at liquid nitrogen temperature by irradiation in the *F* band. During such bleaching an absorption peak appears at 8750A. When during subsequent gradual heating the *F* and V_1 absorptions are observed, a pronounced peak appears at −100°C in both "absorption glow curves" indicating that *F* centers and V_1 centers are temporarily restored and subsequently destroyed by thermally activated recombination. The thermal bleaching can be prevented and the restored absorptions be arrested by recooling from −100°C to liquid nitrogen temperature. The formation of the V_1 band on warming (conditional on *F* irradiation at low temperature) is particularly remarkable in the case where the crystal after x-raying had been raised to room temperature so that at the beginning of the experiment it did not contain any V_1 centers at all. The experiments suggest that the electrons released by low-temperature *F* bleaching are trapped in metastable centers (possibly associated with the peak at 8750A) which also contain a positive hole, and that the thermal breakup of these centers yields *F* and V_1 centers in close proximity to each other.

* 1953–54 at Duke University, Durham, North Carolina.

B14. Phosphorescence of and Energy Storage in Some Ultraviolet Emitting Phosphors.* C. E. MANDEVILLE AND H. O. ALBRECHT, *Bartol Research Foundation.*—Measurements of the phosphorescent decay of uv excited NaCl−Tl show its uv and visible emission bands to decay by distinctly differing laws, whereas the bands of KCl−Tl under α particle and uv excitation appear to have approximately the same mode of decay. The "light storage" properties of NaCl−Ag have been investigated as a function of silver concentration. The photostimulated emission of x-ray excited thick crystals of NaCl−Ag has a maximum at a silver concentration of a few tenths of a percent by weight and shows a marked decline at concentrations as great as one percent by weight. The energy storage properties of x-rayed beryllium oxide have been observed. By drawing short photostimulated bursts of uv from the phosphor at least once every 48 hours over a period of days, it has been concluded that BeO retains in deep traps stored electrons for a greater time (thermal escape is less probable) than does NaCl−Ag of the most favorable silver concentration. The absolute emission of BeO under both excitation and photostimulation is less than that of NaCl−Ag, but the BeO is powdered and thus has poor transmission properties.

* Assisted by the joint program of the U. S. Office of Naval Research and the U. S. Atomic Energy Commission.

B15. Effect of Pressure on the Optical Absorption of the Activator in a Luminescent Solid. PETER D. JOHNSON AND FERD E. WILLIAMS, *General Electric Research Laboratory.*—The optical absorption spectrum of thallium-activated potassium chloride has been measured at pressures to 2000 kg/cm². The absorption band corresponding to the $^1S_0 \rightarrow {}^3P_1{}^0$ transition of Tl^+ shifts 4A to longer wavelengths. The spectral shift can be calculated from the theory of luminescence of KCl:Tl[1] recognizing that the occupation probabilities of accessible atomic configurations of the activator system are dependent on pressure and the transition energy for a particular configuration is not. The probability $Q(\epsilon,P)$ of the transition energy ϵ at the configuration q with the applied pressure P is $Q(\epsilon,P) = Q_0(\epsilon) \exp\{[AP/kT][q-(AP/2K)]\}$, where $Q_0(\epsilon)$ is the probability of the transition energy ϵ with no applied pressure, A is the effective area of the activator system and K

is the force constant determined from the quantitative configuration coordinate model. The area A is determined by assuming that the pressure acts hydrostatically on six pistons each of cross section equal to the cross sectional area of the Cl^-. The theoretical shift in absorption is 5A to longer wavelengths.

[1] F. E. Williams, J. Chem. Phys. **19**, 457 (1951); J. Phys. Chem. **57**, 780 (1953).

B16. Light Decay from Electroluminescent Phosphors.* S. H. AUTLER AND W. F. ROAT, *Lincoln Laboratory.*—A series of studies has been made on powdered electroluminescent phosphors. The phosphors which were of the ZnS:Cu:Pb blue-green type were excited by sharp pulses of current of the order of a microsecond in duration. The pulse of light which followed each current pulse was detected by a photomultiplier after passing through a monochromator. The decay of the light intensity was recorded for several thousand microseconds and was thus observed during a period when the plate was not being excited. The decay rate depended on the wavelength of the light, but in all cases the light fell off much slower than either a linear or bimolecular process would predict. A second current pulse applied in the same direction before the light has ceased completely results in a momentary decrease in output. This suggests that, before emission occurs, electrons must diffuse back to the emission centers from which they have been pulled by the original electric field. Irradiating the phosphor with infrared has marked effects upon its light output and this will be discussed.

* The research in this document was supported by the U. S. Army, Navy, and Air Force under contract with the Massachusetts Institute of Technology.

THURSDAY MORNING AT 10:00

Shoreham, West Ballroom

(E. C. CREUTZ presiding)

Apparatus of Nuclear Physics, I

C1. Proposed Design of a 50-Mev Proton Linear Accelerator.* L. H. JOHNSTON, E. A. DAY, AND J. H. WILLIAMS, *University of Minnesota and Midwest Accelerator Conference.*—Requirements for the injection of protons into a multi-billion volt alternating gradient accelerator indicate the following desirable properties: (a) high energy to minimize frequency modulation and effects of space charge, gas scattering, and remanent guide field; (b) small energy spread and good collimation to allow capture of injected protons into small aperture; (c) large pulse currents. An Alvarez-type single-cavity accelerated with the following characteristics is proposed. Injector energy ½ Mev, length 80 feet, radio-frequency 200 megacycles, peak rf power 6 megawatts, maximum repetition rate 1 per second, rf pulse length 200 microseconds, proton pulse length as required by alternating gradient machine, output energy 50.0±0.2 Mev, anticipated instantaneous current more than 0.1 milliamperes. Steel vacuum enclosure with bonded copper lining also serves as resonant cavity. Diameter tapered from 42 in. to 36 in. to maintain uniform 6-in. diameter drift tubes. Magnetic quadrupole lenses inside each drift tube provide radial focussing. Initial proton aperture 1 centimeter, final 2 centimeters. Anticipated beam diameter 1 centimeter, angular deviation ±1 milliradian.

* Partially supported by the U. S. Atomic Energy Commission.

C2. Ionization Loading of Electrostatic Generators. C. M. TURNER, *Brookhaven National Laboratory.**—Back streaming electrons in a positive ion acceleration tube generate x-rays upon striking materials at the anode end of the tube. Recent tests show that ionization of the high-pressure insulating gas used in electrostatic generators by this x-ray flux, contributes significantly to the well known difficulties which accompany the application of high potentials to an acceleration tube. Not only is the charging current requirement increased excessively by this extraneous ion load, but ions precipitated onto the potential grading hoop system upset the otherwise uniform gradient along it and thereby invite sparking. The ratio of these ionization currents to the primary back electron current can be as high as 40 at 2 million volts and 150-psig tank pressure. Variations of anode geometry from a simple steel plate to a composite of beryllium and lead designed to minimize x-ray production and maximize x-ray absorption, increased the voltage limitation on the 8 foot long acceleration tube in the rebuilt Brookhaven National Laboratories research electrostatic generator from 2.5 million to close to 4 million.

* Work performed under the auspices of the U. S. Atomic Energy Commission.

C3. Rf Cockcroft-Walton Generator for Neutron Production.* R. A. PECK, JR., *Brown University.*—A 200-kev deuteron accelerator has been constructed for spectroscopy of relatively low-yield (n,p) reactions, utilizing the $D+T$ reaction for neutron production. The high-voltage source is of the rf Cockcroft-Walton type[1] and consists of six doubler units sealed in oil-filled plastic drums. The stack of doublers is excited by a 45-kc oscillator (20-kv peak) and each unit provides 40-kv dc, without power load. Ripple components[2] and dc output have been observed at frequencies of 45 kc, 800 cps, and 60 cps. Voltage output under load improves markedly with change from 60 to 800 cps but changes little above 800 cps. The ion source is of the rf type and has produced currents up to 15 ma, with higher currents apparently obtainable if desired;[3] several milliamperes (at 200 kev) have been obtained on a 10-cm² target blank. Some features of design and construction will be discussed and performance characteristics described.

* Supported in part by the U. S. Atomic Energy Commission.
[1] J. R. Woodyard, Rev. Sci. Instr. **22**, 705 (1951) and UCRL-694.
[2] E. Everhart and P. Lorrain, Rev. Sci. Instr. **24**, 221 (1953).
[3] H. P. Eubank, Phys. Rev. **92**, 853 A (1953).

C4. A Pressurized 500-Kilovolt High-Frequency Cockcroft-Walton Accelerator.* PAUL LORRAIN, R. BÉIQUE, P. GILMORE, P. E. GIRARD, A. BRETON, AND P. PICHÉ, *Université de Montréal.*—A 24-stage high-frequency Cockcroft-Walton accelerator (1), (2) has been built which accelerates positive ions to 500 kev. For compactness, it is pressurized at 10 psig in a tank 38 inches in diameter and 53 inches long. A single oscillator and power amplifier unit is used to feed the voltage multiplying circuit, the filament transformers, and the power supplies for the source and the extracting electrode. There are no moving parts, aside from control rods which serve to direct and focus the beam, burn the source on and off, and admit

gas to the source while the accelerator is in operation. A PIG-type ion source is used (3), (4). Focussing is obtained by means of a single extraction electrode which operates as an *einzel* lens.

* Supported in part by Canadian Atomic Energy Control Board.
[1] Paul Lorrain, Rev. Sci. Instr. **20**, 216 (1949).
[2] Edgar Everhart and Paul Lorrain, Rev. Sci. Instr. **24**, 221 (1953).
[3] Paul Lorrain, Can. J. Research **A25**, 338 (1947).
[4] Paul Lorrain, Helv. Phys. Acta **XII**, 497 (1948).

C5. Particle Selection Technique Used at the M.I.T. Cyclotron.* F. A. ASCHENBRENNER, *M.I.T.*—The particle selective counter consists of a thin plastic scintillation counter which measures dE/dx of the reaction particles and a NaI(Tl) counter which measures the remaining energy of the reaction particles after they pass through the thin counter. The product $E \cdot dE/dx$ which is proportional to the mass over a limited energy range is taken electronically and displayed on one axis of an oscilloscope. The energy is displayed on the other axis. The product and energy pulses are also sent through two pulse height analyzers. Output pulses from the analyzers actuate a coincidence circuit. The coincidence pulses trigger the intensity grid of the oscilloscope when the pulses on the two axes are at their maxima. Time exposure photographs of the oscilloscope show separate lines representing the resolved particles of different mass and also individual particle energy groups. The bias and gate of the product analyzer can then be adjusted so that only one type of particle is counted. The other analyzer can then be used to obtain the energy spectrum of the type of particle selected.

* This work has been supported in part by the joint program of the U. S. Office of Naval Research and the U. S. Atomic Energy Commission.

C6. Microtrons (Electron Cyclotrons for X and K Band Operation) II.[1] H. F. KAISER, *Naval Research Laboratory.*—Three microtrons under study and development will be discussed: (1) a *K* band (24 Kmc) microtron which has been observed to operate in a low-energy mode; (2) a general purpose *X* band (9375 mc/sec) microtron which is being used to test microtron ideas and is suitable for electron and x-ray experimental research, including studies on extracted electron beams; (3) a high-power 1-megwatt *X* band microtron incorporating experience gained in design and operation of *X* band microtrons to-date. Development of the *K* band microtron depends at present on improvement of resonators and increase of available power, both of which are feasible. The *X* band microtron is easily operated with commercially available magnetrons and forms an easily operated and dependable accelerator for energies of several Mev.

[1] H. F. Kaiser, Phys. Rev. **91**, 456 (1953); J. Franklin Inst., Feb., 1954.

C7. Phase Properties of the Deflected Ion Beam from a Fixed-Frequency Cyclotron. M. JAKOBSON, *Montana State University*, AND J. H. MANLEY, *University of Washington.*—The duration of the ion burst and the phase of the dee voltage as the deflected ion beam emerges from the University of Washington Cyclotron has been investigated. This knowledge is necessary for the measurement of reaction energies with a time of flight spectrometer. The ions were detected by means of a stilbene crystal mounted on a 1P21 photomultiplier. The photomultiplier signals were sent to the vertical amplifier of a 517 Tektronix. A rf pickup coil at the deflector provided the horizontal sweep and time base. The ions are sharply defined in phase at threshold. As the dee voltage is increased above threshold, and with the magnetic field tuned to resonance, the duration of the ion burst increases rapidly at first, then approaches a constant value. The ions emerge earlier in time as the magnetic field is *increased* through resonance. As different turns appear, a jump in time of arrival of the ions occurs. The phases of the emerging ions have been obtained by numerical integration and are in agreement with measurements.

C8. Betatron Orbit Stability as a Function of *n*. G. C. BALDWIN, F. R. ELDER, AND W. F. WESTENDORP, *General Electric Research Laboratory.*—Experiments are in progress with a small betatron with symmetrical magnetic circuit and polepiece profile designed to produce a guide field exponent $n=0.7$ constant over a wide annular region. With low rate pulsed operation, n can be varied linearly from 0.5 to 0.9 by concentric polepiece windings excited by a current transformer. Reduced output and weak x-radiation throughout the acceleration cycle, indicating instability, are observed for discrete n values of 0.53, 0.56, 0.64, 0.75, >0.84. Theoretical analysis shows these to be the result of interaction with azimuthal guide field variations.[1]

[1] D. M. Denison and T. Berlin, Phys. Rev. **69**, 542 (1946); D. Judd, Ph.D. thesis, California Institute of Technology (1950).

C9. Spectral Distribution Curves of the Far Ultraviolet Radiation from the Cornell Synchrotron.* D. H. TOMBOULIAN AND P. L. HARTMAN, *Cornell University.*—Based on Schwinger's[1] theory, numerical calculations have been carried out for the purpose of comparison with recent[2] experimental observations of the electromagnetic radiation emitted by high-energy electrons. Tentative intensity distributions curves have been obtained from the spectrograms on the basis of certain assumptions regarding the distribution of energy among the different order spectra produced by the grating. Utilizing the narrow emission bands of certain light elements as the incident radiation, a determination of the actual grating response is in progress. More complete reduction of the experimental data must await the outcome of the current work on the efficiency of the grating.

* Supported by the Office of Ordnance Research, U. S. Army.
[1] J. S. Schwinger, Phys. Rev. **75**, 1912 (1949).
[2] P. L. Hartman and D. H. Tomboulian, Phys. Rev. **91**, 1577 (1953).

C10. A Gaseous Scintillation Counter. C. EGGLER AND C. M. HUDDLESTON, *Argonne National Laboratory* (introduced by Louis A. Turner).—A photomultiplier tube has been used to measure the light emitted by argon and certain other gases when excited by α particles. A thin film of plastic color shifter has proved effective for converting spectral lines in the far ultraviolet into the region of photocathode sensitivity. Preliminary experiments, using a simple geometrical arrangement and a Pu source of known activity, indicate a counting efficiency approaching 100 percent. Pulse-height analysis strongly suggests the possibility of using a gaseous scintillation counter for heavy-particle spectral analysis.

C11. Measurement of the Time Jitter in BF_3 Counters. O. D. SIMPSON, *Phillips Petroleum Company.**—Time jitter or the variations in time delay after a neutron is absorbed until the α pulse is recorded has been measured for some commercial BF_3 counters. The gamma rays from the 470 kev level in Li^7 were detected by means of NaI crystal α photomultiplier and used to trigger an oscilloscope trace. By measuring the α-particle pulse number-time distribution, the time jitter was determined. A counter of 2-in. diameter, 60 cm of Hg BF_3, and 2-mil center wire showed variations of $2\frac{1}{2}$ μsec (the time between 50 percent of maximum probability values). A counter of 1-in. diameter, 65-cm Hg BF_3, and a 6-mil center wire showed variations of 0.5 ± 0.1 μsec. Factors involved in BF_3 counting characteristics are discussed with emphasis upon fast neutron chopper detectors.

* Work carried out under contract with the U. S. Atomic Energy Commission.

C12. Scintillation Detector for Thermal and Epithermal Neutrons. K. H. SUN, P. R. MALMBERG, AND F. A. PECJAK, *Westinghouse Research Laboratories.*—Thermal and epithermal

neutron detection by scintillation counters as compared with that by gas-filled counters has the advantages of simplicity, ruggedness, compact geometry, and better time resolution. Gamma insensitive neutron phosphors made from mixtures of boron-containing substances and ZnS−Ag have been investigated in great detail recently.[1–4] A phosphor of this type has been prepared from a glycerol borate plastic containing 20 weight percent boron mixed with du Pont 1410 (10 micron) ZnS−Ag. The low viscosity of the melted boron plastic at 200°C facilitates the thorough mixing with the ZnS−Ag which is essential to optimum counting efficiency and permits molding of the phosphor into any desired shape. Using disk-shaped phosphors and a Du Mont 6292 photomultiplier, optimum counting rates have been observed for a ZnS−Ag to boron plastic ratio of 2 and a thickness of about 1 mm. Estimated counting efficiencies for thermal neutrons greater than 10 percent have been attained using ordinary boron. A much greater efficiency is expected with enriched B^{10}.

[1] Palevsky, Muether, and Stolovy, Bull. Am. Phys. Soc. **28**, No. 6, 16 (1953).
[2] C. O. Muehlhause, BNL 242 (T-38). Also BNL 1953 Ann. Rep., p. 10.
[3] D. E. Alburger, BNL 1233.
[4] Gatti, Germagnoli, Persano, and Zimmer, Nuovo cimento (9), **9**, 1012–21 (1952).

C13. Vapor Expansion Chamber Using Pure Water. I. J. E. Hopson and C. E. Nielsen, *Ohio State University.*—A cloud chamber operating on pure water vapor has been built and operated. Provisions have been made for having a volume defined expansion of vapor, free from condensation nuclei and air, into a vacuum. Some important operating points are: a. by pumping on water it can be caused to supply vapor free of condensation nuclei. b. The chamber will hold a vacuum in the micron range thereby assuring the purity of the operating vapor. c. During expansion the vapor must not be in contact with a free liquid surface. d. After each expansion the entire system is pumped out and a new supply of vapor is used. Thus there are no reevaporation nuclei left in the chamber. e. The present chamber operates from an initial pressure of from one to two centimeters of mercury; thus, it is ideal for the study of low-energy ionizers. f. With suitable valves and vacuum pump the time interval between useful expansions can be less than 15 seconds. g. Clear alpha-particle tracks without background with a ratio of final to initial volumes of 1.7 with the initial temperature of the water at that of the room were observed.

C14. Vapor Expansion Chamber Using Ammonia and Water. II. R. P. Caren and C. E. Nielsen, *Ohio State University.*—The vapor expansion method of cloud-chamber operation in which after each expansion into an evacuated volume the chamber is refilled with clean vapor was tried with an ammonium hydroxide vapor source; good tracks were obtained. With this method of operation there is simultaneous cooling of the vapor in the chamber and heating of the vapor entering the expansion volume, and sensitive time characteristics approach those of Wilson chamber expansion to constant pressure. Expansion of the vapor in the chamber is less than in the Wilson chamber with the same ratio of final to initial volume, and the temperature ratio, given by $T_1/T_2=(V_2/V_1)^p$, is here found by using $p=(\gamma-1)/\gamma$. Pressure may be varied by varying the concentration of ammonia in the vapor source. In experiments involving stopping power the similarity of ammonia and water makes vapor composition relatively unimportant. This chamber is simple in construction, requires no clearing expansions, and may be operated at any desired pressure above the vapor pressure of water.

C15. Vapor Expansion Chamber Using Pure Gases at Low Temperatures. III. C. E. Nielsen and J. E. Hopson, *Ohio State University.*—A cloud chamber operated as described in the preceding abstracts has been cooled in liquid nitrogen and used with nitrogen vapor. With the ratio of final to initial volume constant, supersaturation obtained has been varied by varying the amount of undersaturation of the vapor before expansion. Ion tracks are observed from a minimum supersaturation of about two and one-half up to the maximum supersaturation of about five obtainable with the present apparatus. Uniform condensation on vapor aggregates is negligible in this range of supersaturation. Experiments with oxygen and argon are in progress; it is found that no condensation occurs in clean oxygen with supersaturations up to about six, the maximum yet studied. At these temperatures evaporation from the vapor source is so slow that an effective expansion is possible with a pool of liquid in the chamber. One could therefore use a Wilson chamber if it were desired. Droplets in nitrogen grow very rapidly, so that if tracks are to be photographed, the time delay between track formation and exposure must be made unusually short.

Thursday Morning at 10:00

Sheraton Park, Burgundy Room

(B. T. Matthias presiding)

Low-Temperature Physics

D1. The Effect of Temperature Scales on Low-Temperature Calorimetric Data. J. R. Clement, *Naval Research Laboratory.*—In correlating calorimetric and elastic data via Born-von Kármán theory, the Debye characteristic temperature for the lattice heat is usually the basis of comparison. For such correlations, a reliable estimate of the uncertainty in the absolute value of the caloric results is important. This fact has led to an investigation of the effect of uncertainties in the liquid helium vapor pressure-temperature scale on the absolute reliability of calorimetric data below 4.2°K. Certain apparent "anomalies" in some older data can be practically eliminated by correcting the data from the temperature scale in use at the time of the original experiments to the presently accepted (1949) scale. Furthermore, uncertainties in Debye temperatures deduced from data based on the 1949 scale have been considered in view of measured deviations from this scale.[1,2] For a hypothetical material having an electronic heat equal to the lattice heat at 10°K, an error in Debye temperature as large as 15 percent may occur around 1.5°K.

[1] J. Kistemaker, Physica **12**, 272 (1946).
[2] L. D. Roberts and R. A. Erickson, Phys. Rev. **91**, 488 (1953).

D2. Methods of Spinning Rotors at Low Temperatures.* J. W. Beams and J. B. Breazeale, *University of Virginia.*—Two methods of spinning rotors at high speeds at liquid helium temperatures are described. In the first method, the

rotor is spun inside a tubular vacuum chamber on the end of a vertical small diameter, long, stainless steel hypodermic needle tube. The hypodermic needle shaft and rotor are driven and supported by an air-driven, air-supported turbine[1] located above the chamber. The chamber is sealed by a vacuum gland around the shaft. Vibrations in the long shaft are suppressed by properly spaced Teflon guides and special dampers. The rotor may be evacuated through the hollow shaft. In the second method the rotor is suspended inside a glass vacuum chamber by the axial magnetic field of a solenoid.[2] The solenoid is outside and coaxial with the Dewars containing the cooling liquids. The rotors are accelerated and driven around a vertical axis by a rotating magnetic field in a way similar to that of the armature of an induction or synchronous motor. The latter method is preferable if slight heating is to be avoided. In both methods the chambers surrounding the rotors are cooled by liquid helium surrounded by liquid nitrogen. Applications of the methods will be discussed.

* Supported by the Office of Ordnance Research.
[1] Beams, Revs. Modern Phys. **10**, 245 (1938).
[2] Beams, Young, and Moore, J. Appl. Phys. **17**, 886 (1947).

D3. The Magnetic Dependence of the Thermoelectric Power of Bismuth at Low Temperatures. J. BABISKIN AND M. C. STEELE, *Naval Research Laboratory.*—Measurements have been made on the thermoelectric power of polycrystalline bismuth wire (0.020-in. diam, 10 in. long, 99.98 percent purity) against copper as a function of temperature and magnetic field at liquid helium temperatures. The lower junction was maintained at 4.2°K in liquid helium. The temperature of the upper junction (which was above the bath) ranged from 4.2°K to 10°K and was measured by a calibrated carbon thermometer. The thermoelectric power was found to vary from 6μv/°K at 5°K to 11μv/°K at 9°K in zero field. Upon applying a uniform longitudinal magnetic field of 70 gauss, the thermoelectric power increased ~10 percent. This is a much larger effect than that observed previously[1] at room temperature in stronger magnetic fields. Further increase of the field showed that thermoelectric power increased less rapidly and appeared to approach saturation at ~400 gauss, when the upper junction was at ~8°K. Preliminary measurements have also been made on a bismuth single crystal in transverse and longitudinal magnetic fields. While the thermoelectric power at zero field was somewhat higher than for the wire, fields up to 100 gauss produced much more pronounced effects than for the wire.

[1] C. W. Heaps, Phys. Rev. **31**, 648 (1928).

D4. The Temperature Variations of the Elastic Constants of Copper Single Crystals from 4.2°K to 300°K. JOHN GAFFNEY AND W. C. OVERTON, JR., *Naval Research Laboratory.*—Using a previous developed cryogenic technique[1] together with an ultrasonic pulse technique, we have measured the adiabatic elastic constants of oriented single crystals of copper from 4.2°K to 300°K. The room temperature measurements are in excellent agreement with those of Lasarus,[2] while at 4.2°K the values of C_{11}, C_{12}, and C_{44} were found to exceed those at room temperature by 4.8 percent, 2.8 percent, and 8.6 percent, respectively. The experimental technique, measured crystal thickness corrections, and uncertainties of the elastic constants will be discussed. The Hooke's law atomic force constants for nearest and next-nearest neighbor interaction for the copper lattice have been obtained from these elastic constants by the relations $\alpha = ac_{44}$ and $\gamma = a(C_{11} - C_{12} - C_{44})/4$ where "a" is the lattice constant. The extrapolated value of γ/α at 0°K is -0.0946.

[1] W. C. Overton, Jr. and R. T. Swim, Phys. Rev. **84**, 758 (1951). W. C. Overton, Jr., thesis, Rice Institute, 1950.
[2] D. Lasarus, Phys. Rev. **76**, 545 (1949).

D5. Correlation Techniques for Testing the Born-von Kármán Theory of Specific Heats. W. C. OVERTON, JR., AND J. R. CLEMENT, *Naval Research Laboratory.*—Two essentially independent elements enter the complete theory of the lattice heat of a crystalline solid: (1) specific heat calculations using vibration spectra based on Born-von Kármán theory, and (2) an atomic model relating the microscopic atomic force constants, α and γ, to the macroscopic elastic c_{ij}'s. Critical testing of the complete theory requires both experimental caloric and elastic data, a combination not generally available. An apparent failure of the theory would not be traceable specifically to either of the two theoretical elements by the usual testing procedures. With the appropriate theoretical calculations, one phase of our technique critically tests element (1) independently, requires only caloric data, and yields numerical values of α and γ. These calorically deduced values of α and γ may then be compared with values derived from the experimental c_{ij}'s through any atomic model,[1,2] this comparison providing an independent test of element (2). The atomic model used by Leighton[1] has been verified experimentally for copper, for which the necessary low-temperature elastic constants[3] are available.

[1] R. B. Leighton, Revs. Modern Phys. **20**, 165 (1948).
[2] J. de Launay, J. Chem. Phys. **21**, 1975 (1953).
[3] W. C. Overton, Jr. and J. Gaffney (to be published).

D6. The Thermal Conductivity of Gallium Single Crystals at Low Temperatures.* HARMON H. PLUMB AND JULES A. MARCUS, *Northwestern University.*—The principal thermal conductivities of Gallium single crystals were measured in the liquid hydrogen and helium temperature range using helium gas thermometers. Gallium of 99.94 percent purity, obtained from the Aluminum Company of America, was grown into cylindrical single crystals (3 mm in diameter and 10 cm in length) by a method similar to that described by Powell.[1] For each specimen, the cylinder axis was parallel to one of the three principal crystallographic directions to within 5°. For one set of crystals the maxima of the thermal conductivity occurred at 6°K and yielded the ratio $c:a:b$ as 1:2:4.5 with the value 3.8 watt/cm°K for the conductivity in the c direction. Another set with maxima at 4°K yielded the ratio $c:a:b$ as 1:3.7:—with the value 10.6 watt/cm°K for the c direction. In the liquid helium range the thermal conductivity fell off rapidly with temperature extrapolating to zero at $T = 0$°K for all crystals. In the liquid hydrogen region both sets of crystals yielded a ratio of approximately 1:3:6 (as compared with 1:3.2:7 for electrical conductivities[1]) with the value 0.4 watt/cm°K for the conductivity in the c direction at 20°K.

* Supported by the National Science Foundation.
[1] R. W. Powell, Proc. Roy. Soc. (London) **A209**, 525 (1951).

D7. The Electrical and Thermal Conductivity of Magnesium and a Magnesium Alloy at Low Temperatures. D. A. SPOHR* AND R. T. WEBBER, *Naval Research Laboratory.*—The minimum of electrical resistance found at low temperatures in some of the dilute alloys of magnesium[1] is sufficiently pronounced to make possible a search for a corresponding effect in the thermal conductivity. We have measured the electrical and thermal conductivity over the temperature range 1.5 to 20°K in two polycrystalline specimens: (1) "pure" Mg, and (2) Mg−0.043 percent Mn. The pure specimen showed a slight minimum in electrical resistance and a thermal conductivity which followed, within experimental error, the dependence on temperature ($1/K = 1/AT + BT^2$) usually found in pure metals in this temperature range.[2,3] The dilute alloy specimen showed a much more pronounced electrical resistance minimum (ρ increased about 10 percent as the temperature was lowered from 4.2 to 1.4°K) and an exactly corresponding depression of the thermal conductivity so that the Lorenz ratio ($K\rho/T$) maintained a value of $(2.64 \pm 0.02) \times 10^{-8}$ (Volt/°K)^2

at temperatures below 4°K. These conclusions are in qualitative agreement with those reported recently by Herlin.[4]

* Now on leave at Clarendon Laboratory, Oxford.
[1] H. E. Rorschach, Jr. and M. A. Herlin, Proc. Schenectady Cryogenics Conf., p. 151 (Schenectady, New York, 1952).
[2] K. Mendelssohn and H. M. Rosenberg, Proc. Phys. Soc. (London) **A65**, 385 (1952).
[3] Kemp, Sreedhar, and White, Proc. Phys. Soc. (London) **A66**, 1077 (Nov. 1, 1953).
[4] Paper presented by M. A. Herlin at the Third Intern. Conf. of Low Temp. Phys. and Chem., Houston, Texas [December, 1953 (unpublished)].

D8. The Thermal Conductivity of Indium-Thallium Alloys at Liquid Helium Temperatures. RONALD J. SLADEK,* *University of Chicago.*—The thermal conductivity of indium specimens containing 0, 5, 15, 20, 30, 38, and 50 atomic percent Tl have been measured as a function of temperature down to 1.3°K and as a function of applied magnetic fields below T_c. The normal state results agree at least qualitatively with the quasi-free electron theory of metals, and the superconducting state results agree with Hulm's suggestion that superconducting electrons do not scatter phonons.[1] A thermal resistivity maximum was found to accompany the isothermal destruction of superconductivity by either a longitudinal or a transverse magnetic field in specimens containing 15 percent Tl or more.[2] Scattering of phonons at boundaries between superconducting and normal regions of the specimen may be responsible for this effect.

* U. S. Atomic Energy Commission predoctoral fellow, 1951–1953. Present address: Westinghouse Research Laboratories.
[1] J. K. Hulm, Proc. Roy. Soc. (London) **A204**, 98 (1950).
[2] R. J. Sladek, Phys. Rev. **91**, 1280 (1953).

D9. The Low-Temperature Magnetization of Two Cerium Salts. WARREN E. HENRY, *Naval Research Laboratory.*—The $^2F_{5/2}$ ground state of Ce^{+++} with one unpaired f electron is of interest because any crystalline electric field asymmetry leaves the essential Kramers degeneracy.[1] A low-lying doublet[2] in Ce^{+++} exhibiting no hyperfine structure is convenient for low-temperature demagnetizations. Thus a sphere of small crystals of cerous nitrate hexahydrate has been magnetized to practical saturation, using a method previously described.[3] If M is plotted against H/T, superposition of magnetic isotherms is observed. A Brillouin function for $J_z=\pm\frac{1}{2}$ and $g=2.1$ seems applicable in the range, 1.3°–4.2°K, for fields up to 60 000 gauss. Similar magnetization of $3Mg(NO_3)_2\cdot 2Ce(NO_3)_3\cdot 24H_2O$ was performed. Although this salt is magnetically more dilute than cerous nitrate, nonsuperposition of isotherms is observed. Since marked anisotropy[4] has already been observed for a single crystal of the double salt, a discussion will be given on the possible role of a crystalline anisotropy field in the observed nonsuperposition of isotherms.

[1] J. H. Van Vleck, *Electric and Magnetic Susceptibilities* (Oxford University Press, London, 1932), p. 296.
[2] R. J. Elliott and K. W. H. Stevens, Proc. Roy. Soc. (London) **215**, 437 (1952); W. G. Penney and R. Schlapp, Phys. Rev. **41**, 194 (1932).
[3] W. E. Henry, Phys. Rev. **87**, 229 (1952).
[4] Cooke, Duffus, and Wolf, Phil. Mag. **44**, 6 (1953); K. S. Krishman and A. Mookherji, Phil. Trans. Roy. Soc. **A237**, 135 (1938).

D10. The de Haas-van Alphen Effect in Zinc at Liquid Oxygen Temperatures. TED G. BERLINCOURT AND M. C. STEELE, *Naval Research Laboratory.*—Recently, McClure and Marcus[1] measured the magnetic susceptibility of zinc in magnetic fields up to 9.5 kilogauss and found a field dependence in χ_{11}, the component of susceptibility parallel to the hexagonal axis, at temperatures as high as 85°K. We have extended these measurements to 25 kilogauss in the temperature range 55 to 90°K and have observed oscillations in χ_{11} equally spaced in reciprocal field as is characteristic of the de Haas-van Alphen effect. However, in the range investigated the period of oscillation β/E_0 is not temperature independent, as it is below 20°K,[2] but increases with increasing temperature. For example, β/E_0 is 6.7×10^{-5} gauss^{-1} in the region 2 to 20°K and rises to 9.8×10^{-5} gauss^{-1} at 55.4°K and 13.4×10^{-5} gauss^{-1} at 70°K. Such a temperature dependence might arise from alteration of the overlap of the pertinent Brillouin zone by the Fermi surface brought about by thermal expansion of the crystal.

[1] J. W. McClure and J. A. Marcus, Phys. Rev. **84**, 787 (1951).
[2] L. Mackinnon, Proc. Phys. Soc. (London) **B62**, 170 (1949).

D11. An Estimate of the Lifetime of Positrons in Superconductors. M. DRESDEN, *University of Kansas.*—It has been suggested[1] that there might be two factors which would cause the annihilation characteristics of positrons in superconductors to be different from those in normal conductors. Preliminary experiments of Talley and Stump[2] and Millett[3] appear to indicate some such effects. One of the factors involved, the change in the *ortho-para* positronium conversion rate has been investigated. It was found advantageous to use the collective description of the electron gas as given by Bohm and Pines. The estimated conversion rate depends rather sensitively on the (unknown) wave function of the system. On the basis of the qualitative nature of this wave function one may conclude that the long-lived component of the positron life time should become longer with decreasing temperature, to a limit of about 3.10^{-7} sec. The precise temperature dependence of this life time should give rather detailed information about the wave function in the superconductive state.

[1] M. Dresden, Phys. Rev. (to be published).
[2] Talley and Stump, Bull. Am. Phys. Soc. **29**, 2 Abstract G9.
[3] Millett, Bull. Am. Phys. Soc. **29**, 2 Abstract G8.

D12. (Abstract withdrawn.)

D13. Effect of Pressure on the Superconducting Transition of Tin.* M. GARBER AND D. E. MAPOTHER, *University of Illinois.*—The shift in the superconducting transition curve under hydrostatic pressure has been measured for a pure single crystal ellipsoid of tin. Pressures up to 100 atmos were applied with liquid helium and the superconducting transition observed by a sensitive ballistic induction technique. Our measurements give a value of -0.0065 ± 0.0002 gauss/atmos. This value is within the range recently reported by Fiske.[1] The transition curve measured at 1 atmos is observed to be lowered by about 0.1 gauss by several applications at helium temperature of the maximum pressure. This may explain why previously reported shifts[2,3] (in which the method used prevented cycling the pressure at low temperature) are generally 15 to 20 percent greater than those of the present work.

* This work supported in part by the Office of Ordnance Research.
[1] M. D. Fiske, Houston Low Temperature Conference.
[2] Kan, Sudovstov, and Lazarew, J. Exptl. Theoret. Phys. U. S. S. R. **18**, 825 (1948).
[3] P. F. Chester and G. O. Jones, Phil. Mag. **44**, 1281 (1953).

D14. Superconductivity of a Precipitation Hardening Aluminum Alloy.* R. E. MOULD† AND D. E. MAPOTHER, *University of Illinois.*—Measurements of the critical magnetic field down to about 0.8°K have been made on a precipitation hardening Al alloy (Al plus about 1.1 percent Mg_2Si) in various conditions of heat treatment. In the hardened condition the H_c *vs* T curve is displaced parallel to itself in the direction of lower temperatures, the effect being superficially similar to the isotope effect and about the magnitude of the largest isotope shifts observed. This shift can be understood in terms of the stress field produced by the Mg_2 Si which precipitates as submicroscopic particles, coherent with the parent Al lattice.[1] In the quenched condition (Mg and Si in supersaturated solid solution) and in the fully annealed condition (Mg_2 Si precipitated and stresses released) the H_c *vs* T curves closely reproduced those of pure Al. The width of the observed transitions indicates that the stress field in the hardened alloy is quite uniform.

* This work was supported in part by the Office of Ordnance Research
† On leave from Preston Laboratories, Butler, Pennsylvania.
[1] A. H. Geisler and J. K. Hill, Acta Cryst. 1, 238–252 (1948).

D15. The Attenuation of Second Sound in Liquid Helium II. W. B. HANSON* AND J. R. PELLAM, *National Bureau of Standards.*—A continuous wave technique was used for the measurement of the temperature amplitude attenuation coefficient or second sound in the temperature range from 1.25°K to 2.17°K. The high frequencies employed (from 100 kc/sec to 268 kc/sec), and the low second sound velocity gave rise to a well defined beam of second sound, thus obviating the need for containing walls in the second sound cell. The frequency squared dependence of the attenuation was quantitatively verified and good agreement with the latest variant of Khalatnikov's theory was obtained for both the magnitude of the attenuation and its temperature dependence. The expected rapid rise in attenuation near the λ point was observed.

* Submitted in partial fulfillment of the requirements for the degree of Doctor of Philosophy from George Washington University.

D16. An Atomic Theory of Liquid Helium. D. TER HAAR, *St. Andrews University, Scotland.**—Under the above title Feynman[1] has recently published two papers in which he shows how one can approximate the exact partition function in such a manner that one can study possible transitions. It is shown how one can derive an approximate partition function similar to the one obtained by Feynman through neglecting the noncommutability of the potential energy operator and the kinetic energy operator, using a method introduced by Kramers in the theory of the equation of state.[2] In this way one gets an explicit expression for the density function entering Feynman's partition function.

* On leave of absence at Purdue University.
[1] R. P. Feynman, Phys. Rev. **91**, 1291, 1301 (1953).
[2] For a description of this method, see: D. ter Haar, *Elements of Statistical Mechanics* (Rinehart and Company, Inc., New York, 1954), pp. 184–188.

THURSDAY MORNING AT 10:00

Sheraton Park, Caribar Room

(E. FEENBERG presiding)

Theoretical Physics, I: Nuclear Theory

DA1. Effect of Nuclear Charge on Internally Produced Pairs. G. K. HORTON AND E. PHIBBS, *University of Alberta.*—The angular distribution of internally created pairs has been used with increasing frequency to study the energy levels of light nuclei. Apart from the exact calculations of Jaeger and Hulme of the total cross section for $Z=84$, the only available theoretical estimates of the transition probabilities are those based on the 1st Born approximation. It can easily be seen that this is not adequate when little kinetic energy is available for one of the components of the pair. This often cannot be avoided, as in No^{24} where a continuous β spectrum only leaves about 0.28 Mev kinetic energy for the positrons. We have calculated the angular distribution of pairs using the Coulomb wave functions dicussed previously by one of us.[1] The results for electric and magnetic dipole, and electric quadrupole transitions, nuclear charges from 10–50, and transition energies varying from one Mev to seven Mev, with various distributions of the energy among the positron and the electron, will be presented. Significant deviations from the 1st Born approximation results have been found. A comparison with the available experimental evidence will be made.

[1] G. K. Horton and R. T. Sharp, Phys. Rev. **89**, 885 (1953).

DA2. Energy Levels in a Spheroidal Well. STEVEN A. MOSZKOWSKI, *University of California, Los Angeles.*—The problem of the energy levels in a deformed nucleus was first discussed by Rainwater,[1] who treated the nuclear potential as a spheroidal well with infinitely high walls. Let the axes of the spheroid be $R(1+d)$, $R(1+d)^{-\frac{1}{2}}$, and $R(1+d)^{-\frac{1}{2}}$. Then the energy levels are given by: $E_N = E_N^{(0)} + dE_N^{(1)} + d^2E_N^{(2)}$. $E_N^{(0)}$ is the energy of a nucleon in a spherical well of radius R. $E_N^{(1)}$ was calculated by Rainwater as function of the quantum numbers n, l, and m. Spin orbit coupling was not taken into account. An explicit formula for the next term $E_N^{(2)}$ has now been derived for the above case by solution of the wave equation in spheroidal coordinates. The results of these calculations can be applied to various features of nuclear structure; e.g., the contribution of kinetic energy to surface energy, and the trend of quadrupole moments with nucleon number.

[1] J. Rainwater, Phys. Rev. **79**, 432 (1950).

DA3. Refinement of the Uniform Model.* EVERETT MARK HAFNER, *Cavendish Laboratory and University of Rochester.*—Wigner's theory of the symmetric Hamiltonian is applied to a description of the energies of 60 states in light nuclei of even mass, $4 \leq A \leq 40$. In addition to the usual assumptions of this model, we make two new ones (*i*) that the theory applies to 0+ states, and (*ii*) that the nuclear volume over which interaction integrals are to be taken is of the form $(a+bA^{\frac{1}{3}})$, where a and b are approximately constant over the entire region, and accurately constant over local regions. To a first approximation, interaction integrals are determined empirically by examining the *relative* energies of 0+ configurations differing by 2 neutrons, assuming that $a=0$ and $b=1.47\times10^{-13}$ cm. We then seek a second approximation by fitting the *absolute* energies of 19 of the known 0+ ground states. We find that the 12 remaining known 0+ states (10 of which are excited, including the states at 2.72 Mev in B^{12}, 7.68 in C^{12}, and 6.05

in O^{16}) are given accurately. The model predicts the energies of 29 states as yet unmeasured. The nuclear radii to which we are led are in agreement with those given by neutron scattering.

* Research supported by the National Science Foundation.

DA4. Theory of Elastic Scattering of Alpha Particles by Heavy Nuclei. J. S. BLAIR, *University of Washington.*—A semiclassical model is used to interpret recent experiments of Farwell and Wegner[1] on the elastic scattering of 15–40 Mev alpha particles by heavy nuclei. In this model the outgoing lth partial wave is assumed to vanish if the corresponding classical turning point is less than the radius of the nucleus plus that of the alpha particle; otherwise it has a phase characteristic of pure Coulomb scattering. The theory predicts that the sum of nuclear and alpha particle radii is approximately equal to the classical apsidal distance evaluated at the energy for which the experimental cross section is one quarter of the corresponding Rutherford cross section. There is fairly good agreement between the calculated and experimental cross sections.

[1] G. W. Farwell and H. Wegner, Phys. Rev. (to be published).

DA5. Numerical Calculation of the Stripping Angular Distribution.* W. TOBOCMAN AND M. KALOS, *Cornell University.*—Calculations of the (dp) cross section which include the Coulomb interaction are being carried out with the help of an I. B. M. card programmed computer. So far we have calculated two cases—one in which the neutron is captured with orbital angular momentum $l=0$ and the other corresponding to angular momentum $l=2$. We find that the only effect of the Coulomb interaction in the $l=0$ case is to enhance the second peak of the angular distribution of the liberated protons. The effect of taking the Coulomb interaction into account for the $l=2$ case is to displace the peak of the angular distribution to larger angles and to broaden the peak somewhat. The calculations are being extended to other cases, and the effects due to the interaction of the protons with the residual nucleus and the scattering of the incident deuteron beam will also be included.

* Supported by the joint program of the U. S. Office of Naval Research and the U. S. Atomic Energy Commission.

DA6. Coulomb Effects in Deuteron Stripping.* N. AUSTERN, *Cornell University,* AND S. T. BUTLER, *Australian National University.*—We have now succeeded in finding a simple and accurate approximation scheme for including the nuclear Coulomb field into the deuteron stripping calculation. Fourier expansion of the hypergeometric function parts of the Coulomb wave functions yields the stripping amplitude in the form of a rapidly converging series of, essentially, non-Coulomb stripping amplitudes. The interpetation of the formulas is very direct, and it is easy to see that the Coulomb effects tend not to give large changes in the angular distribution.

* Supported by the joint program of the U. S. Office of Naval Research and the U. S. Atomic Energy Commission.

DA7. Isotopic Spin Factors in Nuclear Reactions.* R. J. DRACHMAN† AND D. C. PEASLEE, *Columbia University.*—Heavy-particle reactions among low states of light nuclei should exhibit statistical factors for isotopic spin in the following way: $\Gamma_{A\times B}=kP\gamma^2C_x^2$. Here C_x is a Clebsch-Gordan coefficient between the isotopic spins of the nuclear states A, B and the emitted particle x; and k, P, γ^2 are the usual particle wave number, penetration factor, and reduced width. Since $C_x^2\leq 1$, isotopic spin conservation generally makes a further reduction in Γ. Experimental evidence for C_x^2 may be obtained by comparing the observed Γ_p and Γ_n for excitation of equivalent compound nuclear states with $T_B=T_A+\frac{1}{2}$. In this case $C_n^2/C_p^2=(2T_A+1)$. Application of these and related considerations will be made to p and n reactions on Li^7.

* Work supported in part by the research program of the U. S. Atomic Energy Commission.
† National Science Foundation Predoctoral Fellow.

DA8. Supermultiplet Evidence from Isotopic Spin Spacing.* D. C. PEASLEE, *Columbia University.*—Let $\Delta(TT')=E(T)-E(T')$ be the energy difference between the lowest states of isotopic spins T and T' in a given nucleus. From β-decay energies and Coulomb-energy estimates, derived from other β-decay energies, we can estimate Δ for light nuclei where isotopic spin should be relatively valid. $\Delta(\frac{3}{2}\frac{1}{2})$ and $\Delta(10)$ for even-even nuclei show a general tendency to decrease with increasing A but remain in the range 5–15 Mev. In striking contrast, $\Delta'(10)$ for odd-odd nuclei is small ($\lesssim\frac{1}{2}$ Mev for $A>18$) and even slightly negative for $A>30$. This qualitative difference is in accord with a supermultiplet structure in which nucleon-nucleon forces are not very spin dependent. On a strict j-j coupling model, however, $\Delta'(10)\approx 0$ implies that $\Delta(TT')\approx 0$ for $T'<T\leq(j+\frac{1}{2})$. The observed values of Δ are thus additional evidence in support of supermultiplet structure in light nuclei.

* Work supported by the research program of the U. S. Atomic Energy Commission.

DA9. Spin Correlations in Neutron Scattering by Gases. A. C. ZEMACH AND R. J. GLAUBER, *Harvard University.*—Spin correlations within a molecule, resulting from the symmetry requirement imposed by nuclear statistics, are well known to affect the scattering of low-energy neutrons. The additional interference terms which arise in the presence of identical nuclei are proportional to the incoherent rather than the coherent scattering cross sections. These effects have been evaluated for polyatomic molecules by an elaboration of a technique described earlier.[1] The complementary symmetries of the spatial and spin dependences of the wave functions permit separation of the required averages over spin and spatial orientations, although the wave functions are not themselves separable. It is thereby shown explicitly that the effects of correlation are quite small in most polyatomic molecules, save at very low temperatures. Typical results, assuming thermal equilibrium, are that the cross section in the forward direction is reduced by 1 percent in gaseous methane at 45°K and by 6 percent in gaseous ammonia at 200°K. These figures decrease rapidly with increasing temperature.

[1] A. C. Zemach and R. J. Glauber, Bull. Am. Phys. Soc. **29**, No. 1, 53 (1954).

DA10. Reorientation of Aligned Nuclei. N. R. STEENBERG,* *National Research Council, Canada.*—It is known that magnetic couplings in the intermediate state affect angular correlations. When nuclei aligned at low temperatures decay by, for example, a β-γ cascade such couplings (external field and hfs) may be expected to influence the degree of alignment of the γ-emitting state and thus the angular distribution. This effect can be conveniently incorporated into the statistical matrix of the γ-emitting state. In many cases of experimental interest the ionic state is a doublet having anisotropic hfs, $(AS_xI_x+BS_xI_x+BS_yI_y)$. Then when $kT<A$ and the lifetime, τ, of the intermediate state is not long a very explicit expression for the degree of nuclear alignment Δ of the γ-emitting can be derived. This is dependent on the external field, the magnetic moment of the intermediate state and on τ, and is immediately applicable to the angular distribution. It is found (1) that reorientation may either increase or decrease Δ, (2) that a strong external field cancels the effect altogether, and (3) where $B=0$ the coupling has no effect on Δ. Where τ is very long, Δ tends to a finite limit.

* National Research Laboratories Postdoctorate Fellow.

DA11. Nuclear Shapes at Half-Filled Shells. BENJAMIN SEGALL, *University of California, Berkeley.*—In the coupled individual-particle collective-mode model of the nucleus,[1] the centrifugal pressure of the individual particles (or holes) in excess of a closed shell distorts the nucleus spheroidally. The

addition of "particles" into a shell, in general, tends to make the shape increasingly oblate, while an increase in the number of "holes" causes the shape to become more prolate. A question that arises is whether in the transition between regions of oblate-shape stability to regions of prolate-shape stability (i.e., at a half-filled shell), the nucleus takes on an axially symmetric or an asymmetric deformation. Calculations were carried out for the $J=5/2$, $7/2$, $9/2$, and $11/2$ shells assuming a strong interaction between the particles and surface, and the results showed that the ground state energies for half-filled shell nuclei are essentially independent of shape. The fact that the symmetric shape is not decidedly favored implies that the "strong coupling approximation" of Bohr and Mottleson[1] is inapplicable in these cases. Thus the simple rotational spectra and large separation of rotational and vibrational levels resulting from that approximation would not be expected to arise.

[1] A. Bohr, Kgl. Danske Videnskab. Mat. fys. Medd. **26**, No. 14 (1952); and A. Bohr and B. Mottelson, Kgl. Danske Videnskab. Mat.-fys. Medd. **27**, No. 16 (1953).

DA12. Level Structure of Li^6.* D. H. LYONS AND A. M. FEINGOLD, *University of Pennsylvania.*—The splitting produced by the tensor force of the S and D states of Li^6 has been computed by a variational method which includes the effect of configuration interaction.[1] It is found that the tensor force contributes, on the average, about 12 Mev to the binding energy, the major part coming from excited configurations. In addition, the ^3D states are split in essentially the same manner as would result from a vector-type force in first order. A total multiplet splitting of 5 Mev is obtained, with the $^3D_3$ state lowest. The tensor force also separates the $^1S_0$ and $^3S_1$ states and the $^1D_2$ and ^3D states, giving a final level structure for Li^6 in qualitative agreement with the known experimental data.

* Supported in part by the joint program of the U. S. Office of Naval Research and the U. S. Atomic Energy Commission.
[1] A. M. Feingold, Ph.D. thesis, Princeton University, 1952.

DA13. Pairing Effects in the Coulomb Energies of Mirror Nuclei.* I. TALMI AND B. C. CARLSON, *Princeton University.*—The Coulomb energies of the mirror nuclei have been written by Feenberg and Goertzel[1] in the form $E_c(Z)=\frac{1}{2}Z(Z-1)a+[Z/2]b$, where $[Z/2]$ is the largest integer not exceeding $Z/2$. The first term represents an average Coulomb interaction, and the second term is a pairing energy. If a and b were strictly constant, the difference between the members of a mirror pair would be $\Delta_1(Z)=E_c(Z)-E_c(Z-1)=(Z-1)a+\frac{1}{2}[1+(-1)^Z]b$. When Δ_1 is plotted directly, or after division by $Z-1$, the pairing effects become inconspicuous at higher Z because of the unequal weighting of a and b. This can be avoided by taking second differences, $\Delta_2(Z)=\Delta_1(Z)-\Delta_1(Z-1)=a+(-1)^Zb$, and the experimental data are sufficiently accurate to justify this procedure. A plot of second differences shows that the pairing effects do not disappear at higher Z, and that some evidence of shell structure appears at $Z=6$, 8, 14, and 20. More accurate data would be particularly desirable for S^{31} and Cl^{33}. Theoretical estimates of a and b will be discussed.

* Supported by the Higgins Scientific Trust Fund and the U. S. Atomic Energy Commission.
[1] E. Feenberg and G. Goertzel, Phys. Rev. **70**, 597 (1946).

THURSDAY MORNING AT 10:00

NBS, East Building

(L. S. TAYLOR presiding)

Invited Papers

E1. Radiation and the Dynamics of Cell Division. CORNELIUS TOBIAS, *University of California, Berkeley.* (45 min.)

E2. Effects of Irradiating Small Fractions of Individual Dividing Cells (motion pictures). R. E. ZIRKLE, *University of Chicago.* (45 min.)

E3. Molecular Structure and Biological Control Mechanism. CYRUS LEVINTHAL, *University of Michigan.* (45 min.)

THURSDAY AFTERNOON AT 2:15

Shoreham, West Ballroom

(N. F. RAMSEY presiding)

Magnetic Resonance and Allied Topics

Invited Paper

F1. Electronic Wave Functions in Metals in Relation to Nuclear Magnetic Resonance. HARRY JONES, *Imperial College (London) and Carnegie Institute of Technology.* (30 min.)

Contributed Papers

F2. Method for Detection of Pure Quadrupole Resonances.* P. J. BRAY, *Rensselaer Polytechnic Institute.*—The very sensitive dispersion detection technique employed by Gutowsky[1] in magnetic moment measurements would require a tracking receiver for application to quadrupole resonance detection. However, the quench frequency of a self-quenched super-

regenerative oscillator depends logarithmically on signal amplitude and, since it is about a thousandth of the oscillation frequency, does not present tracking problems. In present experiments, a convenient harmonic of the quench frequency of a frequency modulated self-quenching superregenerative oscillator is detected with an HRO 60 receiver. AM slope detection of the expected quadrupole resonance modulation of the quench frequency is used with oscilloscope presentation of the receiver output. The presented signal is a dispersion-type curve for each super-regenerative side-band detection of the quadrupole resonance. Signal-to-noise ratios obtained with this detection method surpass those achieved in this laboratory[2,3] with plate-current-detection techniques. Signal-to-noise comparisons and quadrupole resonance data obtained with this quench variation method will be given.

* Research supported by the Rensselaer Polytechnic Institute Research Grants Committee.
[1] Gutowsky, Meyer, and McClure, Rev. Sci. Instr. **24**, 644 (1953).
[2] P. J. Bray and P. J. Ring, J. Chem. Phys. **21**, 2226 (1953).
[3] P. J. Bray and D. Esteva, J. Chem. Phys. (to be published).

F3. Intensities of the Zeeman Components of Quadrupole Transitions in Sodium Chlorate.* YU TING AND DUDLEY WILLIAMS, *Ohio State University*.—The Zeeman pattern of the Cl^{35} nuclear quadrupole transition is a single crystal of sodium chlorate has been studied in a field of 6000 gauss. The shifts of the observed lines from the zero-field frequency for various orientations of the crystal in the external field were in close agreement with theoretical predictions.[1] At orientations in which the angle between one direction of electric-field symmetry and the direction of H field approached 90°, rapid changes in the intensities of the observed components were noted. Two of the four Zeeman components diminished in intensity and disappeared at 90°. The other two Zeeman components increased in intensity and reached a maximum at 90°. The transformation matrix, which diagonalizes the total Hamiltonian at this orientation (with zero electric field asymmetry factor), can be obtained in closed form. The calculated probability of magnetic dipole transitions shows that the disappearance of the components in question is indeed to be expected.

* Supported by Office of Scientific Research, Air Research and Development Command, Baltimore, Maryland.
[1] C. Dean, Ph.D. thesis, Harvard University (1952).

F4. Random Pulses and Electron-Spin Line Widths in Metals.* D. L. FALKOFF, *Brandeis University and Lincoln Laboratory*.—Dyson[1] has given a theory which accounts well for the observed[2] line width and line shape for electron-spin resonance in plates of lithium and sodium which are thick in comparison with the skin depth. By treating the diffusion of the conduction electrons, the absorption line for the bulk samples was found to depend on the diffusion time T_D, which a conduction electron spends in the skin depth as well as on the skin relaxation time T_2. But for samples not much larger than the skin depth, it is more appropriate to consider the random motion of the individual conduction electrons in and out of the skin depth rather than the average diffusion. Analysis of the resulting random time series shows that the line width can also depend on the mean recurrence time T_r between successive sojourns in the skin depth. This effect will depend on the ratio of sample width to skin depth.

* The research in this abstract was supported jointly by the U. S. Army, Navy, and Air Force under contract with the Massachusetts Institute of Technology.
[1] Unpublished Harvard Lecture, January 4, 1954.
[2] G. Feher and T. W. Griswold, Bull. Am. Phys. Soc., **28**, No. 7, 18 (1953).

F5. Conduction Electron Spin Resonance Absorption in Sodium.* I. H. SOLT, JR., AND M. W. P. STRANDBERG, *M.I.T.*—In order to understand more clearly the degree of spin-orbit coupling experienced by the conduction electrons in metals, an accurate measurement has been made of the g value of the spin resonance absorption in sodium. Colloidal suspensions of sodium particles (less than 4 microns in size), ultrasonically dispersed in paraffin wax, were investigated at 9000 Mc/sec. The measured g values are $g=2.0012\pm0.0002$ at 300°K and 78°K, and $g=2.0014\pm0.0002$ at 4°K. These values disagree outside the range of experimental error with the value of 2.0019 calculated by Yafet.[1] Line-shaped and line-width measurements were also made. The observed line shape was asymmetric and could be explained as the sum of the real and imaginary parts of the susceptibility where the imaginary part had a Lorentz shape. The line width at the half-power points of the imaginary part of the susceptibility was 11.5 gauss at room temperature and decreased linearly with temperature. This corresponds to a relaxation time of about 5×10^{-9} sec at room temperature.

* This work was supported in part by the U. S. Army Signal Corps, the Air Materiel Command, and the U. S. Office of Naval Research.
[1] Y. Yafet, Phys. Rev. **85**, 478 (1952).

F6. Paramagnetic Resonance Absorption in Ammonium Chrome Alum.* CHARLES F. DAVIS, JR., AND M. W. P. STRANDBERG, *M.I.T.*—A study has been made of the paramagnetic resonance absorption in diluted single crystals of ammonium chrome alum at room temperature. Work was done at X, S, and K band and at various orientations of the crystal. These data have been checked with the theoretical predictions of line intensity and position (based on the assumption that the chromium ion is in an electric field of trigonal symmetry). Paramagnetic resonance spectra of single ammonium chrome alum crystals at 77°K have been studied in an attempt to explain the anomalous two splittings of the ground state.

* This work was supported in part by the U. S. Army Signal Corps, the Air Materiel Command, and the U. S. Office of Naval Research.

F7. Paramagnetic Resonances in Glasses.* R. H. SANDS,† J. TOWNSEND, AND H. P. HOOD,‡ *Washington University*.—Work has been in progress for the past year and one-half on paramagnetic absorption spectra in glasses. Samples containing known amounts of impurities, furnished us by the Corning Glass Works, have been studied by means of a microwave spectrometer operating near 9000 Mc/sec. These and other samples show absorption lines lying close to apparent g values of 2, 4, and 6. These three lines do not always occur in the same sample. A tabulation of these g values will be presented together with representative line shapes. The influence of Stark splittings on the line shapes will be discussed and some theoretical results shown.

* Assisted by the joint program of the U. S. Office of Naval Research and the U. S. Atomic Energy Commission.
† Heermann-Mallinckrodt Fellow.
‡ Research and Development Division Corning Glass Works, Corning, New York.

F8. Paramagnetic Resonance in Organic Free Radicals at Low Fields.* R. S. CODRINGTON, J. D. OLDS, AND H. C. TORREY, *Rutgers University*.—We have measured the magnetic resonance line shapes of the solid organic free radicals: diphenylpicryl hydrazyl, tri-p-anisylaminium perchlorate and tri-p-aminophenylaminium perchlorate as a function of magnetic field at the frequencies 0.8, 1.5, 4, 8, and 15 Mc. At 15 Mc all show two Lorentz shaped resonances symmetrically disposed about zero field with full widths between inflection points of 2.0, 0.68, and 0.33 oersteds, respectively. As the frequency is lowered, the resonances merge in each case to form a single absorption maximum at zero field. For each radical the entire shape is accurately predicted by a set of Bloch equations modified so that longitudinal relaxation is parallel and transverse relaxation perpendicular to the instantaneous field direction. The usual Bloch equations give completely erroneous results at low frequencies. In every case the oscillating field was sufficiently small that no longitudinal

relaxation effects were observed. For each radical a single T_2 obtained from the width at 15 Mc sufficed to reproduce all details of the shapes. The resonance lines of these radicals at 9 300 Mc are significantly wider than at 15 Mc probably due to diamagnetic anisotropy at high fields.

* Supported by the U. S. Office of Naval Research.

F9. Paramagnetic Resonance Absorption of $VOSO_4 \cdot 5H_2O$. M. B. PALMA,* M. U. PALMA,* AND D. PALUMBO, *University of Palermo* (introduced by M. W. P. Strandberg).—The microwave paramagnetic resonance absorption (in X band) of the V^{++++} ion in vanadylsulphate has been examined at the Institute of Physics of the University of Palermo. This ion is, together with the Ti^{+++} ion, the only example of paramagnetic ions of the iron group which have only one electron in the 3d shell. In the salts in which it has been studied, the Ti^{+++} does not show any absorption at room temperature because of the very short relaxation time.

The experimental results and their theoretical interpretation will be given. Further experiments at different frequencies and temperatures are being carried out at the Microwave Spectroscopy Laboratory, Research Laboratory of Electronics, M.I.T.

* Now at Research Laboratory of Electronics, M.I.T.

F10. Magnetic Resonance Enhancement in a Multilevel System.* JAMES H. BURGESS,† *Washington University* (introduced by G. E. Pake).—In any system with more than two energy levels one can cause the steady state population distribution to depart from its thermal equilibrium value by applying a perturbation affecting only a single pair of levels. Thus other observable transitions of the system will be altered in intensity. For those transitions involving one of the perturbed pair there will be a first-order broadening. The free radical $ON(SO_3)_2^=$ exhibits a hyperfine structure of six levels which can be examined by magnetic resonance techniques.[1] Calculations show that other π transition intensities are enhanced or diminished depending upon the transition saturated. Experiments at 31 gauss yield, for the most favorable case, an enhancement ratio of 1.2 in substantial agreement with calculations. Besides a small constant broadening, a "bump" occurs which shifts with the saturation oscillator frequency in a field sweeping experiment. When centered in the line the "bump" increases the width by a factor of 1.8. Curves will be shown and possible explanations for the "bump" discussed.

* Assisted by the joint program of the U. S. Office of Naval Research and the U. S. Atomic Energy Commission.
† Washington University Fellow.
[1] Townsend, Weissman and Pake, Phys. Rev. **89**, 606 (1953).

F11. Nuclear Magnetic Resonance in Some Solid Hydrocarbons. F. A. RUSHWORTH,* *Union College* (introduced by Harold E. Way).—The nuclear magnetic resonance spectra and spin-lattice relaxation times have been measured for the protons in *n*-pentane, *n*-hexane and cyclo-pentane at temperatures down to 70°K. Molecular motion in the solid state was found in all three cases. For *n*-petane and *n*-hexane the results indicated a reorientation process of the methyl groups at the ends of the molecules, governed by an activation energy of 2.8 kcal/mole. The absorption lines had not broadened to their theoretical rigid widths at the lowest temperatures reached, although the reorientation frequencies at these temperatures were considerably smaller than the line widths. In the case of cyclopentane the lattice was effectively rigid below about 120°K. The uncertainties involved do not allow a distinction to be drawn between the plane and puckered molecular models. Above the temperature of the first transition (122.4°K) considerable molecular motion was occurring, the molecules probably rotating with spherical symmetry. At higher temperatures the second moment of the line shape decreased still further to a very low value, and it is suggested that the molecules were diffusing bodily through the lattice.

* On leave from University of St. Andrews, Scotland.

F12. Magnetic Moment of the First-Excited State of Pb^{204}. V. KROHN AND S. RABOY, *Argonne National Laboratory*.—The effect of a magnetic field on an angular correlation pattern[1] was used to measure the magnetic moment of the first excited state (370 kev) of Pb^{204}. The technique used involved measuring the coincidence rate at 135° and 225° as a function of the magnetic field applied perpendicular to the plane of the two counters. The 905-kev gamma ray was delayed by about 0.4 μsec and the coincidence resolving time was 0.13 μsec. The ratio of the coincidence rates at the two angles as a function of Larmor frequency was calculated by integrating Eq. (74) of Abragam and Pound[2] over the experimental time limits. A value of $g = +0.04 \pm 0.02$ was obtained by comparison of the calculated curve with the experimental data.

[1] Aeppli, Alberg-Schönberg, Frauenfelder, and Scherer, Helv. Phys. Acta **25**, 339 (1952).
[2] A. Abragam and R. Pound, Phys. Rev. **92**, 943 (1953).

F13. Measurements of the Distribution of Velocities in Potassium Molecular Beams. A. BENNETT,* *Carnegie Institute of Technology*.—Extensive measurements of velocity distributions in beams of potassium atoms have been made under various conditions of oven pressure and slit geometry. The measurements confirm the modified Maxwell distribution in the beam, except that the proportion of slow molecules is considerably smaller than that expected for a Maxwell distribution at the source; this deficiency increases with increasing oven pressure and with decreasing molecular velocity. The deficiency is less if the oven slit is a hole in a thin wall than if it is a long canal. The velocity selector comprised two slotted discs, rotated at constant speed; the phase angle between discs was varied to vary the transmitted velocity. The detector was a surface ionization gauge with platinum filament. The results were corrected for the finite width of the selector slits and are believed accurate to within two percent of the maximum amplitude of the spectrum. Calculations show that the sensitivity of the apparatus should be sufficient to observe the distribution of velocities of a molecular beam after reflection from a solid surface.

* Now at Westinghouse Research Laboratories.

THURSDAY AFTERNOON AT 2:15

Shoreham, Main Ballroom

(J. A. HIPPLE presiding)

Apparatus of Nuclear Physics, II; Other Topics in Nuclear Physics

FA1. Scattered Radiation Contribution to Depth Dose Data for 35- and 90-Mev Synchrotron X-Rays. J. BOAG AND B. ZENDLE, *National Bureau of Standards*.—Cavity ionization measurements were made in a masonite phantom of the doses along the central axis due to annular x-ray beams of different radii. Two sets of measurements were made, one with 90-Mev

synchrotron x-rays and a 14.5-meter target to phantom distance and the other with 35 Mev and a 4.5 meter distance. The data are being used to interpret depth dose measurements[1] made with an anthracene crystal and a 14 cm diameter, 39-Mev betatron x-ray beam possessing a nonuniform radial intensity distribution. When this beam is corrected to a plane uniform beam of infinite extent by means of the scattered radiation data, the dose at 45-cm depth is increased about 20 percent. This type of correction to cavity ionization depth dose measurements permits an absolute evaluation at these x-ray energies of the ergs per gm absorbed for 1 esu per cc of ionization measured in water. The scattered radiation data are also useful in interpreting narrow beam-large ionization chamber transition curves.[2]

[1] B. Zendle and H. W. Koch (to be published).
[2] Blocker, Kenney, and Panofsky, Phys. Rev. **79**, 419 (1950).

FA2. The Oxidation Yield of the Ferrous Sulfate Dosimeter by X-Rays.* W. BERNSTEIN, J. WEISS, AND J. B. H. KUPER, *Brookhaven National Laboratory.*—A variety of values have been reported for the absolute yield, G (ferrous ions oxidized per 100 ev of ionizing radiation absorbed in the solution), for the ferrous sulfate dosimeter. Measurement[1] of the energy absorbed by calorimetric and cathode-ray bombardment techniques give a G of 15.8; ionization-chamber measurements vary between 15 and 21. This disagreement between the individual ionization chamber measurements and collectively with the other methods led to this investigation.

A parallel plate ionization chamber and a solution cell with identical sensitive volumes were constructed from polystyrene. 3×10^{-3} M ferrous sulfate in 0.8 NH_2SO_4 solutions were used. The ionization chamber was designed in accordance with the Bragg-Gray principle; extrapolation to zero spacing eliminated the edge effect. The stopping power correction for polystyrene was verified by the use of an identical aluminum chamber for which the average ionization potential is known. The energy, W, to produce one ion pair in air was determined to be 34.4 ev in terms of Jesse's[2] values for A and N_2. The G value obtained was 16.0 ± 0.5, in good agreement with the calorimetric and cathode ray bombardment measurements.

* Work performed under the auspices of the U. S. Atomic Energy Commission.
[1] J. Saldick and A. O. Allen, J. Chem. Phys. (to be published).
[2] W. P. Jesse and J. Sadanski, Phys. Rev. **90**, 1120 (1953).

FA3. Magnetic Spectrograph for Nuclear Disintegration Studies.* W. W. BUECHNER, C. P. BROWNE, H. ENGE,† M. MAZARI,‡ AND C. D. BUNTSCHUH, *M.I.T.*—A sector-type, uniform-field, analyzing magnet has been constructed, following a design proposed by Bainbridge.[1] The entrance and exit faces of the magnet are sections of a circle of radius 50 cm. The magnet gap is one-half inch. The target or source of particles is located approximately 50 cm from the entrance face. Particles with radii of curvature between 37 and 56 cm in the magnetic field emerge from the exit face and are detected on a photographic plate, each exposure covering a range of approximately a factor of 2 in particle energy. With polonium alpha particles and a total acceptance angle of 0.1 radian in the gap plane, peaks of half-width <2 mm are obtained over a length of 75 cm along the plate. The dispersion varies along the plate but is approximately 0.1 percent in energy per mm. The magnet is mounted so it can be rotated about an axis through the source, the angular range being 135 degrees. The spectrographs will be used in conjunction with the ONR electrostatic accelerator.

* This work has been supported by the joint program of the U. S. Office Naval Research and U. S. Atomic Energy Commission.
† Now at the University of Bergen, Norway.
‡ On leave from the National University of Mexico.
[1] K. T. Bainbridge, Solvay Report, 7th Congress in Chemistry, 1947.

FA4. MTR Fast Chopper. R. G. FLUHARTY, *Phillips Petroleum Company.**—A fast neutron chopper (Brookhaven type (*1*)) has been installed at the Materials Testing Reactor and is in successful operation. The resolution is at least 0.1 μsec/m, and for energies below 300 ev, the counting rate is 5000 counts/hr/1 μsec channel. This is about 25 times that quoted by Brookhaven (*2*). The detectors used are 28, 1″ diameter, Al-walled BF_3 proportional counters filled to 65 cm pressure. The counters hang vertically in a 5, 4, 5, 5, 4, 5 array so the neutron path length in the counters is 6″. The "time jitter" of the detectors is 0.5 ± 0.1 μsec (*3*). Present operation uses a 15-meter flight path, but greater distances are planned as a means of using the high flux. The neutron spectrum and use of the instrument to study known resonances will be discussed.

* Work carried out under contract with the U. S. Atomic Energy Commission.
[1] Seidl, Hughes, and Palevsky, Phys. Rev. **89**, 897(A) (1953).
[2] Hughes, Seidl, Palevsky, and Levin, Phys. Rev. **90**, 363(A) (1953).
[3] Simpson, abstract C11.

FA5. MTR Time-of-Flight Instrumentation. D. R. DE BOISBLANC AND K. A. MCCOLLOM, *Phillips Petroleum Company** (introduced by R. L. Doan).—Time-of-flight instrumentation has been designed for use with the MTR Fast Chopper. The circuits used with other fast choppers were not directly applicable because of the loss of information arising from high counting rates expected at the MTR. A well-known time division principle employing two ring scalers in a 10×10 array establishes 100 consecutive channels of equal time duration. A novel feature of the circuitry reduces the dead time between channels to substantially zero by a means not requiring extremely fast pulse rise times. Channel widths of 0.5, 1.0, 2.0, 5.0, 10, and 20 microseconds are available. A continuously adjustable time delay of 0-1000 microseconds initiated by a light pulse in synchronism with the neutron burst is provided. The run-through of the 100 channels commences at the end of the time delay period. Provisions are included for total detector, total channel, in-pile monitor, and background counts.

* Work carried out under contract with the U. S. Atomic Energy Commission.

FA6. Ionization of Pure Gases and Mixtures of Gases by 5-Mev Alpha Particles. T. E. BORTNER AND G. S. HURST, *Oak Ridge National Laboratory.*—In this experiment the charge produced in a large ionization chamber, by the complete stopping of Pu^{239} alpha particles, was measured by a standard null method. From the charge produced the number of ion pairs n was deduced and W defined by the equation $W=E/n$, where E is the energy used in forming the n ion pairs, was computed. The results for a number of pure gases, among them He at 46 ev will be shown. Our results of W for mixtures of gases is described by the formula

$$1/W_m=[(1/W_1)-(1/W_2)]Z+(1/W_2),$$

where $Z=P_1/(P_1+aP_2)$ and W_m is the W for the gas mixture having two components of pressure P_1 and P_2 with W values for the pure gases equal to W_1 and W_2, respectively. It was found that the W value for gas mixtures did not vary linearly for some gases. In a mixture of N_2 and O_2 the a factor is 1.06. The values for a for the mixtures will be given in tabular form.

FA7. Energy Expenditure per Ion Pair in Solids. E. J. STERNGLASS, *Westinghouse Research Laboratories.*—Since the ionization density produced by an electron beam of energy V entering a solid has a pronounced maximum at a mean depth $\bar{d}$ due to scattering of the primaries, and the ejected electrons are absorbed exponentially in metals,[1] the energy expended per ionization $\bar{E}_0$ is obtainable from measurements of Δ, the number of secondaries escaping per incident primary. The internal secondaries are initially randomly directed, and essentially all those reaching the surface can escape as the

surface dipole barrier is small. $\bar{d}$ increases approximately as $V^{\frac{1}{2}}$.[2] Accordingly,

$$\Delta = [V/\bar{E}_0][0.5 \exp(-\beta V^{\frac{1}{2}})],$$

where β is a characteristic constant. Using available data on the secondary yield of 33 metallic and semiconducting elements corrected for backscattering, values of $\bar{E}_0$ were found to be of the same order as for gases, varying periodically with Z from about 20–35 ev, independent of V or the ionization potential.

[1] E. J. Sternglass, "The phenomenon of secondary electron emission from homogeneous solids," thesis, Cornell, 1951; also Report of 13th Annual Electronics Conference, M.I.T. (1953).
[2] N. Bohr, Danske Videnskab. Selskab. **18**, No. 8, (1948), Chaps. 3 and 5.

FA8. Range and Specific Ionization for High-Energy Protons in Nuclear Emulsions. O. HEINZ, *University of California, Berkeley.**—Stacks of nuclear emulsion varying in thickness from 18.35 g/cm² to 56.83 g/cm² were exposed in the external proton beam of the Berkeley cyclotron, and the average specific ionization dT/dx [in Mev(g/cm²)$^{-1}$] was measured by determining the equivalent thickness of Cu needed to remove the same amount of energy from the beam as a given thickness of emulsion. The energies range from 230 to 320 Mev. The emulsion stacks consisted of layers of 200μ Ilford C-2 stripped emulsions of average density 3.81±0.01 g/cm³. The specific ionization was found to be 1.5 percent higher for emulsion than for Cu measured over the same energy interval. From these data the ratio of the mean ionization potentials for emulsion and Cu was determined as $I_E/I_{Cu}=0.89\pm0.09$. The range of 342.5-Mev protons in emulsion was found to be 92.68±0.25 g/cm² which is 1.1 percent lower than the measured range of the same beam in Cu (93.65±0.20 g/cm²). The measured range in emulsion is about 1.5 percent shorter than the value calculated by Vigneron (and extended to higher energies by Barkas). They assumed 332 ev as the mean ionization potential of emulsion. This work was done under the auspices of the U. S. Atomic Energy Commission.

* Now at Bell Telephone Laboratories.

FA9. The Stopping Powers of Metals for Low-Energy Protons.* D. W. GREEN, J. N. COOPER, AND J. C. HARRIS, *Ohio State University.*—The stopping powers for gold, antimony, tin, and manganese have been measured for protons with energies from 400 to 1000 kev by a modification of the technique of Madsen and Venkateswarlu.[1] Thin films of the metals were evaporated directly on thin layers of lithium fluoride which served as targets for the proton beam from a Van de Graaff generator. The resultant displacements of the lithium and fluorine (p,γ) resonances were measured. The curve for the stopping power of gold lies about 10 percent above that of Kahn.[2] A plot of the logarithm of the atomic stopping power as a function of the logarithm of Z reveals that these data and those for copper, selenium, silver, lead, and bismuth as previously reported[3] lie very near a straight line.

* Supported in part by the U. S. Atomic Energy Commission through a contract with the Ohio State University Research Foundation.
[1] C. B. Madsen and P. Venkateswarlu, Phys. Rev. **74**, 648 and 1782 (1948).
[2] D. Kahn, Phys. Rev. **90**, 503 (1953).
[3] Green, Cooper, and Harris, Bull. Am. Phys. Soc. **29**, No. 1, 27 (1954).

FA10. Penetration of 6-Mev Gamma Rays in Lead and Iron. K. SHURE, P. A. ROYS, AND J. J. TAYLOR, *Westinghouse Electric Corporation, Atomic Power Division.*—Measurements of the relative dose rate from 6-Mev gamma-ray source have been taken in water and in air through lead and iron. The lead varied in thickness from zero to eight inches and the iron varied from zero to twelve inches in one-inch steps. The source of the 6-Mev gamma rays was N^{16} produced by circulating demineralized water through the high flux region of the Materials Testing Reactor. The water was then piped to a tightly wound coil of Saran tubing in the form of a flat cylindrical disc which served as a source plate. The anthracene scintillation detector was moved along the axis of the cylindrical disk. The output current from the photomultiplier, which was a measure of the dose rate, was read on a low drift ac electrometer. The relative dose rate has been calculated by the Spencer-Fano[1] method utilizing the results of the joint NBS-NDA computational program.[2] The calculated results agree fairly well with the experimental results.

[1] L. V. Spencer and U. Fano, J. Research Natl. Bur. Standards **46**, 446 (1951); Phys. Rev. **81**, 464 (1951).
[2] Goldstein, Wilkins, and Spencer, Phys. Rev. **89**, 1150 (1953); NDA Memo 15C-20 (1953).

FA11. Calculations on the Penetration of High-Energy Electrons.* L. V. SPENCER, *National Bureau of Standards.*—The Boltzmann equation for electron diffusion and degradation in an infinite homogeneous medium, assuming continuous energy loss and plane geometry, has been reduced by Lewis to a chain of equations in terms of the quantities

$$I_{1n}(t) = \int_{-\infty}^{\infty} dz z^n \int_{4\pi} d\Omega P_1(\cos\vartheta) I(t,\vartheta,z),$$

where $I(t,\vartheta,z)$ is the flux of electrons with residual range t and obliquity ϑ at a distance z from the source plane. Lewis wrote down formal expressions for the $I_{1n}(t)$ but did not use them to reconstruct spatial distributions. We have calculated spatial distributions by utilizing (1) a simple recursion relation existing between the quantities

$$I_{1n}{}^p = \int_0^{\infty} dt t^p I_{1n}(t),$$

which enables easy calculation of $I_{on}{}^p$ for comparatively large n; and (2) the fact that the trend of the $I_{on}{}^p$ for large n (corresponding to the deep penetration tail of $I(t,\vartheta,z)$) agrees with that obtained from a function similar to Yang's thin foil distribution.

* Work supported by the U. S. Office of Naval Research.

FA12. The Transmission of Monoenergetic Positrons and Electrons. H. H. SELIGER, *National Bureau of Standards, and The University of Maryland.*—The transmission as a function of thickness of absorber of monoenergetic positrons and electrons with energies up to 400 Kev has been measured in aluminum and in silver. The absorber forms the window of a 2π proportional flow counter whose counting efficiency is better than 99 percent down to a few hundred electron volts. Particles from a radioactive source are focused into a beam by a 90 degree magnetic analyzer with an energy resolution better than 5 percent. The beam, with a half angle of divergence of 2 degrees, impinges perpendicularly upon the absorber window of the 2π counter so that the total transmission is measured, independent of the forward angle of emergence or of the partial energy loss. In this type of geometry, positrons appear to be more strongly absorbed than electrons in medium and thick absorbers. Possible reasons for the difference between these results and those of other workers[1,2] will be presented. This work is continuing.

[1] K. A. Baskova and B. S. Dzhelepov, Doklady Akad. Nauk. S.S.S.R. **77**, 1001 (1951).
[2] Chang, Cook, and Primakoff, Phys. Rev. **90**, 544 (1953).

FA13. A Formula for Nuclear Masses in Terms of the Electron Mass Involving only Rational Numbers for Light Nuclei. ENOS E. WITMER, *University of Pennsylvania.*—The mass of any nucleus in any state may be represented by Mm, where m is the rest mass of the negative electron. We surmise that M is always an integral multiple of 1/256. For $A \leq 11$, M in the ground state is given in almost all cases to within ±0.1 by the formula

$$M = (7/2)^6 A - (139/64)AB(A)f_1(Z) + (23/64)f_2(A,N). \quad (1)$$

Here $AB(A)$ is always an integer and is 1, 3, 9, 28, 30, 36, 42, and 56 for A from 1 to 8, respectively. $f_1(0)=0$ and $f_1(Z)=1$ for $Z\geq 1$. $f_2(A,N)$ is always an integer and some of the formulas for it are

$$f_2(A,0)=0;\quad f_2(A,1)=1;\quad f_2(A,2)=A+1. \qquad (2)$$

Formula (1) gives the masses of the neutron and proton exactly, m is 0.000548 770 2859 amu.

FA14. Scattering of X-Rays by Nuclei.* G. PUGH,† D. H. FRISCH, AND R. GOMEZ, *M.I.T.*—Bremsstrahlung x-rays of energies from 50 to 135 Mev, produced by the M.I.T. synchrotron, are being scattered from lithium, beryllium, carbon, aluminum, copper, tin, and lead. The x-rays scattered at 45°, 90°, or 135° produce electron pairs in an 0.1-inch lead converter. The total energy of these electrons is measured with a large terphenylcyclohexylbenzene scintillation counter. Preliminary cross sections at 90° are approximately equal to the coherent sum of Thomson scattering by Z free protons in a density distribution which—if uniform—has a radius of between 0.8 and $1.4A^{\frac{1}{3}}\ 10^{-13}$ cm.

* This work has been supported in part by the joint program of the U. S. Office of Naval Research and U. S. Atomic Energy Commission.
† Eastman Fellow.

FA15. Angular Dependence of Annihilation Quanta from the Magnetic Substates of Triplet Positronium.* R. M. DRISKO, *University of Pittsburgh.*—The calculation by Ore and Powell[1] of the angular distribution and spectrum of the annihilation quanta from triplet positronium has been repeated without averaging over spin. The relative number of quanta per unit solid angle and per unit energy interval is found to be $[(1\pm\cos^2\theta)F(k)\pm(1-3\cos^2\theta)f(k)]$, where θ is the angle between the quantization axis and the direction of observation of the quantum, and k is the energy of the quantum in units mc^2. The upper sign refers to the combined and equal contributions of the $m=\pm 1$ substates, the lower to the $m=0$ substate. $F(k)$ is the energy spectrum defined as in reference 1 but with mass set equal to unity.

$$f(k)=\frac{k}{2(2-k)^2}-\frac{(1-k)}{(2-k)^3}\ln(1-k)-\frac{4(1-k)}{k^3}-\frac{(2-k)^2}{2k^3}-\frac{3(2-k)(1-k)}{k^4}\ln(1-k).$$

From this formula, when $\theta=90°$ the $m=0$ substate contributes more than $\frac{1}{4}$ of the quanta, an effect recently observed by Hughes and Marder.[2] Formulas for the polarization and angular correlations of the quanta will also be presented.

* This work was carried out at Carnegie Institute of Technology under U. S. Atomic Energy Commission Predoctoral Fellowship.
[1] A. Ore and J. Powell, Phys. Rev. **75**, 1696 (1949).
[2] See accompanying abstract FA16 by Marder, Hughes, and Wu.

FA16. Effect of Angular Dependence of Annihilation Radiation of Orthopositronium in a Magnetic Field.* S. MARDER, V. W. HUGHES, AND C. S. WU, *Columbia University.*—An effect of the angular dependence of the annihilation radiation from the magnetic substates of orthopositronium has been observed in an experiment similar to that of Deutsch and Dulit.[1] Quanta due to positron annihilation were observed at a direction of 90° to a magnetic field. The fraction of orthopositronium decaying by three-quantum annihilation, f, can then be computed, and at high values of the field f was found to be less than $\frac{3}{4}$. The value $\frac{3}{4}$ is expected statistically since only annihilation radiation of the $M=0$ substate is affected by the field. Our observation is understandable if the angular distribution of the annihilation radiation from the different magnetic substates is considered. Angular distribution formulas are given in the accompanying abstract by R. Drisko. The ratio of singlet to triplet decay rates can be computed from values of f *vs* the field, after corrections are made for the angular distribution. Our data yield $\lambda_s/\lambda_t=1289$ with a statistical probable error of ± 14 percent. This result agrees with the theoretical value 1115.[2]

* This work partially supported by the U. S. Atomic Energy Commission.
[1] M. Deutsch and E. Dulit, Phys. Rev. **84**, 601 (1951).
[2] A. Ore and J. Powell, Phys. Rev. **75**, 1696 (1949).

THURSDAY AFTERNOON AT 2:15

Sheraton Park, Continental Room

(D. E. ALBURGER presiding)

Radioactive Nuclei, I

G1. Beta End-point Energies and Half-Lives for Some Mirror Transitions.* W. A. HUNT, R. M. KLINE, AND D. J. ZAFFARANO, *Iowa State College.*—The positron spectra and half-lives of some short-lived nuclides formed by (γ,n) reactions induced by 70-Mev x-ray irradiation have been reexamined,[1] using an improved scintillation spectrometer with a fast 100-channel pulse-height analysis system[2] and cyclic timing equipment with the synchrotron.[3] Beta spectra from P^{32}, Y^{90}, Cl^{34}, and Li^8 were used for energy calibration, and good statistics were obtained in the half-life measurements. Results are summarized as follows:

Nuclide	End point (Mev)	Half-life (seconds)	ft (seconds)
Mg^{23}	2.95 ± 0.07	$10.7\ \pm0.7$	$3600\pm\ 500$
Si^{27}	3.76 ± 0.08	4.05 ± 0.10	$4000\pm\ 450$
S^{31}	4.50 ± 0.10	2.40 ± 0.07	$5150\pm\ 600$
Ca^{39}	6.10 ± 0.15	0.90 ± 0.05	7250 ± 1000

* Work supported by the U. S. Atomic Energy Commission.
[1] F. I. Boley and D. J. Zaffarano, Phys. Rev. **84**, 1059 (1951).
[2] Hunt, Rhinehart, Weber, and Zaffarano, Rev. Sci. Instr. (to be published).
[3] P. L. Phipps, M.S. thesis, Iowa State College, 1953 (unpublished).

G2. New Isotope Identification Program on the Oak Ridge 86-inch Cyclotron. T. H. HANDLEY AND B. L. COHEN, *Oak Ridge National Laboratory.*—The large currents of 22-Mev protons, the large fluxes of high-energy neutrons they produce, the ready accessibility of enriched stable isotopes, and an auxiliary project on rare earth purification have formed the basis for a program of search for new radioactive isotopes with the Oak Ridge 86-inch cyclotron. Activities are produced by (p,n), $(p,2n)$, $(p,3n)$, (p,pn), (p,α), $(p,\alpha n)$, $(p,2p)$, (n,p), and (n,α) reactions. An empirical systematics of the excitation functions and cross sections for these reactions has been worked out and has been a valuable aid in evaluating impurity problems, in determining mass assignments, and in estimating upper and lower limits to half-lives not observed. Equipment and techniques have been developed for detecting activities between one second and 10^7 years. A total of ten new radioactive species (including seven in the rare earth region) have been positively identified, and seven assignments in recent isotope tables have been disproven. Beta and gamma radia-

tions from all new isotopes have been studied by scintillation spectrometry.

G3. Superallowed Transitions in 4*n*-type Nuclides. M. BOLSTERLI AND E. FEENBERG, *Washington University.**—Recent experimental work[1] on radioactive 4*n*-type nuclides indicates the presence of superallowed components in the decay of Sc^{40}, Cl^{32}, P^{28}, A^{24}, and Na^{20}. Partial half-lives for the superallowed components can be estimated from available information on *dn* thresholds, Coulomb energies, β^+ and γ energies and the *ft* values of the image β^- transitions. In the superallowed component $|\int 1|^2=2$ and $|\int \sigma|^2$ can be computed for special coupling schemes. The *ft* values estimated for the superallowed components are generally consistent with $|\int 1|^2+|\int \sigma|^2>2$.

* Assisted in part by the joint program of the U. S. Office of Naval Research and the U. S. Atomic Energy Commission.
[1] Glass, Jensen, and Richardson, Phys. Rev. **90**, 320 (1953); Glass and Richardson, Bull. Am. Phys. Soc. **28**, No. 7, B3 (1953); A. C. Birge, Phys. Rev. **85**, 753 (1952); L. W. Alvarez, Phys. Rev. **80**, 519 (1950).

G4. Production of Be^7 in High-Energy Reactions.* J. HUDIS, E. BAKER, AND G. FRIEDLANDER, *Brookhaven National Laboratory.*—Cross sections will be reported for the formation of Be^7 in the bombardment of C, Al, Cu, Ag, and Au in the Cosmotron with protons in the Bev energy range. In the case of C the cross section stays substantially constant (near 12 mb) from 1.0 to 2.2 Bev, and is approximately the same in this energy range as at 340 Mev.[1] For the other target elements investigated, the excitation curves show a rise with increasing proton energy and the slopes of the curves increase with increasing Z. At 2.2-Bev proton energy, the cross sections are all of the same order of magnitude, between 1 and 10 mb. The data indicate that, except possibly in the case of C targets, Be^7 is formed not as a residue of nucleon evaporations, but by direct ejection.

* Research carried out under the auspices of the U. S. Atomic Energy Commission.
[1] L. Marquez and I. Perlman, Phys. Rev. **81**, 953 (1951).

G5. The Inner Bremsstrahlung in A^{37} and Ge^{71}.* BABULAL SARAF, *Bartol Research Foundation.*—The experimentally observed spectrum (by scintillation spectrometer) of the inner bremsstrahlung from A^{37} has been compared with the theoretical spectrum, after correcting for the detection efficiency, ratio of full energy peak to Compton distribution, and $I-$x-ray escape peak. The comparison shows good agreement from approximately 300 kev to the end point of the spectrum, but at low energies the emission seems to be larger than the theoretical predictions. The absolute source strength of A^{37} has been measured by proportional counter, and it has been found that the emission probability for the higher-energy part of the spectrum is in agreement with the theory within the probable error of about 30 percent. The spectrum of Ge^{71} has been studied down to 20 kev. It has been found that the emission below ~100 kev is much larger than the theoretical value and exceeds considerably the probable errors. The absolute source-strength has been measured by counting a known fraction of x-rays in a scintillation spectrometer. The emission probability above 100 kev is here also found to be in agreement with the theory within the probable error of about 30 percent.

* Assisted by the joint program of the U. S. Office of Naval Research and the U. S. Atomic Energy Commission.

G6. Double Vacancies in the *K* Shell Associated with *K*-Electron Capture in A^{37}.* J. A. MISKEL AND M. L. PERLMAN, *Brookhaven National Laboratory.*—The pulse-height spectrum produced by the decay of A^{37} in a proportional counter was analyzed to determine the probability, per *K*-electron capture, for the production of a double vacancy in the *K* shell. The double vacancy is produced by promotion of the second *K* electron to a bound state or to the continuum. In these experiments both processes could be observed; the measurements included events in which the kinetic energies of the promoted electrons were in the range zero to 4.0 kev. Eighty-four percent of the theoretically predicted total effect should occur in this energy interval. The data, appropriately corrected, give for the probability of double *K* vacancy production per *K* capture, in the energy interval investigated, $4.8\pm0.8\times10^{-4}$. The result is substantially in agreement with the value calculated from theory.

* Research carried out under the auspices of the U. S. Atomic Energy Commission.

G7. The β Spectrum of K^{42}.* L. KOERTS, A. SCHWARZSCHILD, R. GOLD, AND C. S. WU, *Columbia University.*—The composite β spectrum of K^{42} has been investigated in the magnetic coincidence spectrometer. The high-energy group exhibits the shape of the unique first-forbidden transition and gives an upper energy limit of 3.56 Mev, which agrees with previous investigations.[1] The lower-energy group is investigated by means of the magnetic coincidence spectrometer. The gamma ray is detected by a NaI scintillation counter with a 4′ lucite light pipe. It is particularly interesting to study the shape of the low-energy β group since the results of the $\beta-\gamma$ angular correlation of K^{42} [2] requires a major contribution of the B_{ij} term from the theoretical interpretation based on the single tensor interaction alone. However, the Kurie plot of the coincidence β spectrum is linear from its upper energy limit of 1.97 Mev to about 0.5 Mev within the statistical fluctuations. It can be concluded that the contribution from the B_{ij} term is not overwhelming. Auxiliary experiments show that the excess of electrons below this energy could be attributed to the finite thickness (~1 mg/cm²) and large area ($r=0.8$ cm) of the evaporated source.

* This work partially supported by the U. S. Atomic Energy Commission.
[1] F. Shull and E. Feenberg, Phys. Rev. **75**, 1768 (1949).
[2] D. T. Stevenson and M. Deutsch, Phys. Rev. **84**, 1071 (1951).

G8. Gamma Radiation from K^{42}. N. H. LAZAR AND P. R. BELL, *Oak Ridge National Laboratory.*—The gamma radiation emitted in the decay of K^{42} was investigated in a 3″×3″ right circular cylinder of NaI (Tl) mounted on a Dumont K-1197 photomultiplier. A previously unreported gamma ray at 0.309 Mev was found. From a comparison of its decay with that of the 1.52 Mev gamma ray, it is thought to follow a weak branch of the K^{42} decay. In order to see this gamma ray, the bremsstrahlung from the high-energy beta rays (3.5 Mev) had to be eliminated. This was done by means of a NaI (Tl) absorber whose pulses were placed in anticoincidence with the signal. By this means, inner bremsstrahlung to ~0.2 Mev and degraded radiation from the absorber, as well as external bremsstrahlung from the stopping of the beta rays, were eliminated. It is suggested that a similar technique using an organic anticoincidence absorber might be useful in other applications, for example, in the examination of inner bremsstrahlung.

G9. On the Disintegration of K^{43}. TORSTEN LINDQVIST* AND ALLAN C. G. MITCHELL, *Indiana University.*†—The nuclear spectrum of K^{43} (22.0 hr) has been studied with the help of a magnetic lens spectrograph. K^{43} decays to Ca^{43} emitting five gamma rays having energies 0.369, 0.627, 0.219, 0.393, and 1.00 Mev, the last three being weak. Five beta-ray groups were found, of energies 1.839, 1.218, 0.827, 0.460, and 0.243 Mev, with relative abundance of 1.6, 5.4, 83.1, 5.4, and 4.5 percent, respectively. A disintegration scheme is proposed. The K^{43} was prepared by the reaction $A^{40}(\alpha,p)K^{43}$.

* Supported by the joint program of the U. S. Office of Naval Research and the U. S. Atomic Energy Commission.
† On leave from Physics Department, University of Uppsala, Sweden.

G10. The Disintegration of Ga^{70}.† M. E. BUNKER, J. W. STARNER, AND J. P. MIZE, *Los Alamos Scientific Laboratory.*—The radiations of Ga^{70} (20.3 min) have been investigated with

beta- and gamma-scintillation spectrometers. The radioactive samples were produced by thermal neutron irradiation of gallium oxide enriched in Ga^{69} (98.42 percent). The principle mode of decay is by a ground-state beta transition of energy 1.65 Mev.[1] Examination of the gamma spectrum revealed the existence of two weak gamma rays of energy 1.04±0.01 Mev and 0.174±0.005 Mev. Coincidences have been observed between these gamma rays. The 1.04-Mev gamma, which is involved in <1 percent of the disintegrations, is several times more intense than the 0.174-Mev gamma. On the basis of these facts and the results of $\beta-\gamma$ coincidence studies, it is concluded that there are two weak beta groups leading from Ga^{70} to excited levels in Ge^{70} at 1.04 and 1.21 Mev above the ground state. Log *ft* calculations based on preliminary intensity measurements suggest that both of these low-energy beta transitions are of the allowed type.

† Work performed under the auspices of the U. S. Atomic Energy Commission.
[1] S. K. Haynes, Phys. Rev. **74**, 423 (1948).

G11. The Isomeric States in $_{32}Ge^{75}$ and $_{32}Ge^{77}$. S. B. BURSON, W. C. JORDAN, AND J. M. LEBLANC, *Argonne National Laboratory.*—Neutron irradiation of Ge^{74} and Ge^{76} produces isomeric states in Ge^{75} and Ge^{77}. Using enriched isotopes, we have studied these activities by means of a scintillation coincidence spectrometer and electron spectrographs. Ge^{75m}: The metastable state in Ge^{75} decays with a half-life of 49±2 seconds. The scintillation spectrometer showed one gamma ray of 142±3 kev and no beta rays. *K* and *L* internal conversion lines were observed from which the energy was assigned as 138.5±1.0 kev. (*K*/*L* estimated >3.) Ge^{77m}: Ge^{77m} decays with a half-life of 52±2 seconds. The scintillation spectrometer showed two gamma rays of 159±3 kev and 215±3 kev of nearly equal intensity. (No conversion lines were observed.) These radiations are not in coincidence but the 215-kev gamma ray is in coincidence with a beta ray whose maximum energy was found to be about 2.7 Mev from absorption measurements. The 159-kev gamma ray is not in coincidence with beta radiation. Thus Ge^{77m} decays by at least two processes—a 159-kev transition to the ground state of Ge^{77} and a 2.7-Mev beta ray to a 215-kev excited state in As^{77}.

G12. New Isomers in Br and Cl. GERTRUDE SCHARFF-GOLDHABER AND MICHAEL MCKEOWN, *Brookhaven National Laboratory.**—A systematic search for isomeric transitions with lifetimes of the order of seconds is being carried out by activation with neutrons from the Brookhaven reactor. So far two new activities have been established: (a) In various Cl compounds a γ transition of 660±20 kev with $T_{\frac{1}{2}}=1.0\pm0.2$ sec was found. Bombardment of enriched Cl isotopes[1] showed the activity in the Cl^{37} sample with a cross section of ~5 mb for "pile neutrons." (b) In Br a γ transition of 210±10 kev with $T_{\frac{1}{2}}=5.0\pm0.2$ sec appeared. With the help of enriched isotopes[1] the activity was shown to be produced in the Br^{79} sample with a cross section of ~10 mb for "pile neutrons."

* Under the auspices of the U. S. Atomic Energy Commission.
[1] The enriched isotopes were obtained from Oak Ridge National Laboratory.

G13. Implications of Photonuclear Effect in Zr^{90}. P. AXEL AND J. D. FOX, *University of Illinois.*—The yields of 4.4 minute Zr^{89m} and 78 hour Zr^{89}, both formed from Zr^{90} during betatron irradiation of natural zirconium, have been studied as a function of energy. At any energy *E*, slightly above its 12.3-Mev threshold E_{th}, the yield of spin ½ Zr^{89m} is approximately proportional to $(E-E_{th})^{\frac{3}{2}}$. In contrast, the yield of the spin 9/2 ground state was anomalously small; no activity was detected for betatron energies between the ground-state threshold and the 588-kev isomeric level. The experiment would have detected 1 percent of the yield expected from photonuclear reactions involving small spin changes. These data give direct experimental proof that (1) photonuclear thresholds are sometimes high because the ground-state transition is unobservable and (2) gamma-ray emission predominates over the emission of high angular momentum neutrons which have energies up to 550 kev. This experiment also implies that quantitative photonuclear yield studies can give information about (1) competition between gamma ray and neutron emission, (2) spin changes, (3) relative density of nuclear energy levels of different spins, and (4) the multipolarity of gamma rays absorbed by nuclei.

G14. Radiations from Cd^{115} (43-Days).* JAGDISH VARMA,† *Bartol Research Foundation.*—The disintegration scheme of Cd^{115} has been studied by several groups of investigators with varying results. The data of the present measurements show that three gamma rays are emitted in de-excitation of levels in In^{115} at 0.95, 1.28, and 1.43 Mev. The quantum energies are 1.28, 0.95, and 0.485 Mev, the latter two in cascade. Beta-ray spectra terminate at all levels of In^{115}. The 150-Kev transition between the two higher excited states was not detected in the single counting rate or by coincidence methods. These results are in agreement with those of Engelkemeir.[1]

* Assisted by the joint program of the U. S. Office of Naval Research and the U. S. Atomic Energy Commission.
† Research Fellow, Bartol; permanent address Morena (M.B.) India.
[1] D. W. Engelkemeir, Argonne National Laboratory Report 4717 (April, 1952).

G15. The Disintegration of I^{126}.* MORRIS L. PERLMAN AND JOAN WELKER, *Brookhaven National Laboratory.*—The radiations from I^{126} have been studied with the aid of a coincidence spectrometer. The active material, produced by fast neutron irradiation of KIO_3, was concentrated by means of a Szilard-Chalmers separation. In the electron-capture decay of I^{126} a gamma ray of energy 0.74 Mev was found to occur in cascade with the previously known[1,2] 0.65-Mev gamma ray. The crossover transition also was observed. In the negative beta decay a gamma ray of energy 0.48 Mev occurs in cascade with the previously known[1,2] 0.38-Mev gamma ray; here also a crossover is observed. The relative abundances of these transitions and of the positron transitions and the maximum energy of the positron spectrum were measured. This information, combined with the previously measured ratio of electron-capture decay to beta decay and with the ratio of the abundances of the 0.85-Mev and 1.24-Mev[1,2] beta rays is sufficient to give the abundances of all observed transitions in the decay scheme. Both the *ft* values and the electron capture to positron ratio for the ground-state transition indicate that I^{126} has spin 2 and negative parity in agreement with the assignments neutron $h_{11/2}$ proton $g_{7/2}$.

* Research carried out under the auspices of the U. S. Atomic Energy Commission.
[1] M. L. Perlman and G. Friedlander, Phys. Rev. **82**, 440 (1951).
[2] Marty, Langevin, and Hubert, J. phys. radium **14**, 671 (1953).

G16. *K*-Conversion Electron—Gamma Angular Correlation in Sn^{117}. ROBERT K. GOLDEN AND SHERMAN FRANKEL, *University of Pennsylvania.**—Sn^{117m} was produced by irradiating separated Sn^{116} in the Oak Ridge Low Intensity Testing Reactor. Because of the low specific activity it was necessary to use thick sources and correct the data for electron multiple scattering.[1] Four sources of average thickness 0.35, 0.70, 1.5, and 2.1 mg/cm² were prepared by evaporation onto glass (<0.25 mg/cm²) films. Thickness distributions of all sources were determined by densitometry of radiograms. The experimental angular correlation coefficients, when plotted *vs* the multiple scattering correction factor, followed a straight line which extrapolated correctly to zero correlation at infinite thickness, verifying the accuracy of the scattering correction for large source thicknesses. A least squares fitting of these data extrapolated to $a_2=-0.136\pm0.005$ at zero source thickness, requiring a mixture of M_1 and E_2 in the second $d_{\frac{1}{2}}\rightarrow s_{\frac{1}{2}}$

transition. Comparing this value with the no mixture coefficient (corrected for geometry) of -0.156 ± 0.001 requires a ratio of electric intensity to total intensity δ^2 of 0.0015 ± 0.0005. Details of the extensive scattering corrections will be given.

* This work supported in part by the Office of Ordnance Research.
[1] S. Frankel, Phys. Rev. **83**, 673 (1951).

G17. A Mixed $E1+M2$ Gamma Transition in Nd^{144}.† ROLF M. STEFFEN, *Purdue University*.—An accurate measurement of the angular correlation of the two cascade gamma rays emitted by Nd^{144} yielded the following correlation function: $W(\theta)=1-(0.210\pm0.015)P_2(\cos\theta)$; $A_4<0.01$. This correlation is consistent with the angular momentum assignment 1–2–0 of Alburger and Kraushaar.[1] Nevertheless the first transition is a mixture of dipole (99.9 percent) and quadrupole (0.1 percent) radiation ($\delta=\pi$). The second transition is by pure quadrupole radiation. Polarization direction correlation measurements[2] indicate an over-all parity change in this cascade. The most reasonable parity assignment is 1 (odd)—2 (even)—0 (even), which necessitates the assumption of an $E1+M2$ mixture for the first gamma transition. As compared to the predictions of the independent particle model, the intensity of the $E1$ transition is then reduced by a factor of about 1000. The parity and angular momentum assignments are in good agreement with the intensity of the strong crossover transition.

† Supported by the U. S. Atomic Energy Commission.
[1] D. E. Alburger and J. J. Kraushaar, Phys. Rev. **87**, 448 (1952).
[2] J. N. Brazos and D. M. Roberts (to be published).

THURSDAY AFTERNOON AT 2:15

NBS, East Building

(F. G. BRICKWEDDE presiding)

Chemical and General Physics

H1. Role of the Principal Quantum Number (n) in the Calculation of the Radii of Ions with Low (1^+,2^+,3^+,4^+) Valence. N. EFREMOV, *1061 Intervale Avenue, New York, New York*.—The ion C^{4+}—the smallest among the tetravalent ions—is the primary ion for the calculation and its ordinate[1] is $(n+11)=12$, whereas its abscissa $K(C^{4+})=n=1$. The K value increases by 1 with decreasing atomic number of an element by 1, e.g., $K(C^{4+})=1$, whereas $K(B^{3+})=2$, etc. Consequently, for the next tetravalent ion Si^{4+} which belongs to the Ne-period ordinata as well abscissa will increase by 1. E.g., let us consider the ordinate and abscissas for the quadrupole group of ions with low valence, belonging to the Ne period. The

Ions	Na^{1+}	Mg^{2+}	Al^{3+}	Si^{4+}
Abscissa K	$(n+3)$	$(n+2)$	$(n+1)$	n
Abscissa K	5	4	3	2
Ordinate	$(n+11)$	$(n+11)$	$(n+11)$	$(n+11)$
Ordinate	13	13	13	13
Number of portions $=K(n+11)$	65	52	39	26
Ionic radii in A	0.95	0.76	0.57	0.38

formula for calculation is: $R_i(X)=/'(n+11)K/P$, e.g., $R_i(Al^{3+})=39P=0.57$A. Thus n is ordinata for ions with high[1] valence and abscissa (K) for tetravalent ions.

[1] See Bull. Am. Phys. Soc. **29**, No. 3 (1954).

H2. Deviations from Additivity of the Intermolecular Field at High Densities.* L. JANSEN AND Z. I. SLAWSKY,† *University of Maryland*.—The induced dipole field of an assembly of neutral atoms or molecules is additive up to the second order of approximation with respect to isolated pairs. Nonadditive terms have been evaluated in the attractive field between three atoms by Axilrod[1] and in the repulsive field between three helium atoms by Rosen.[2] At high densities the deformation of the electron clouds by the repulsive part of the potential field cannot be neglected in the zero-order wave functions for the induced dipole interaction. Using the model of a caged molecule and approximating the effect of the repulsive forces by a boundary condition, it is shown that a nonadditive effect exists in the induced dipole field, resulting in a considerable weakening of the attractive field between two molecules. For argon the calculated internal energy on the assumption of additivity of the intermolecular field is too negative by about 100 cal/mole at a density of 600 Amagat.

* Supported by the U. S. Office of Naval Research.
† On the Staff of the Naval Ordnance Laboratory.
[1] B. M. Axilrod, J. Chem. Phys. **17**, 1349 (1949); **19**, 719 (1951).
[2] P. Rosen, J. Chem. Phys. **21**, 1007 (1953).

H3. The Effect of Intermolecular Forces on the Rapid Expansion of a Gas from an Initial Condition of Very High Density and Temperature.* J. M. DAWSON AND Z. I. SLAWSKY,† *University of Maryland*.—Measurements of the expansion rates of nitrogen with initial pressures between 300 atmos and 1000 atmos and initial temperature of 27°C show that clearly in this region the effect of intermolecular forces is to retard the expansion as compared with an ideal gas. In this region the internal energy of nitrogen is negative. It was believed that if the expansion was started in a region of positive internal energy the effect would be an increase in the expansion rate. Since no data was available for a real gas with large internal energy it was impossible to check this experimentally. Therefore, calculations of the expansion rates were made using the results of the high density and temperature free volume calculations of W. Fickett and William W. Wood. Results of these calculations showed as expected that the expansion rate was increased with respect to an ideal gas.

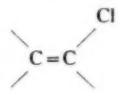
* Supported by the U. S. Office of Naval Research.
† On the staff of the Naval Ordnance Laboratory.

H4. A General Method for High-Speed Machine Computation of Ideal Gas Thermal Properties. The Diatomic Free Radicals of the Isotopic Hydrides.* LESTER HAAR AND A. S. FRIEDMAN, *National Bureau of Standards*.—The partition functions for the free radicals are obtained in closed form. They include terms to account for the special low-temperature effects arising with these molecules, in particular when the ground states are $^2\pi$ states. For the light molecules the splitting of the ground state is further complicated by the uncoupling of the electronic spin to the nuclear axis. In addition the partition function includes first-order corrections for rotation-vibration coupling, rotational stretching, and vibrational anharmonicity. Tables of thermal properties are computed with the aid of the NBS digital computer at 80 temperature intervals from 50° to 5000°K. The results for OH are compared with the term by term computations of the unexpanded partition function available for this molecule.[1]

* Sponsored in part by the U. S. Atomic Energy Commission Division of Research.
[1] Glatt, Adams, and Johnston, O.S.U. Tech. Report No. TR 316–5.

H5. Double Bond Character of the Carbon Chlorine Bond. R. BERSOHN, *Cornell University*.—Double bond character of

the carbon chlorine bond was first proposed by Pauling and co-workers to explain the shortening and lowered reactivity of conjugated C=Cl bonds. From the bond lengths Pauling deduced a double bond character of 15 percent for the C−Cl bond in vinyl chloride. From the quadrupole coupling asymmetry parameter η, Goldstein and Bragg deduced the value of 4 percent. All the published asymmetry data for C−Cl bonds can be explained on the assumption of weak coupling of the Cl π electrons with the C π electrons. The effect of the Cl atoms can then be treated as a weak perturbation on the aromatic system; molecular orbital theory has been used to calculate the double bond character and hence η for a variety of molecules. It is found that η is about 0.10 for linkages of the type



but about 0.25 for

H6. Dielectric Constant of Dioctyl Phthalate Smoke.* H. C. THACHER, JR., AND PAUL B. DORAIN, *Indiana University.*—The difference in dielectric constant between thermally dispersed dioctyl phthalate smokes before and after filtration was measured with a Birnbaum microwave refractometer[1] operating at 9385 Mc/sec. The results fit the equation $\Delta\epsilon/c = 10.8 \times 10^{-10} - 6.86 \times 10^{-12} c$, where c is the concentration of smoke in mg/m³. The dielectric constant difference $\Delta\epsilon$ appears to be independent of particle size. According to the simple theory[2] $\Delta\epsilon/c$ should have the constant value 10.3×10^{-10}, in good agreement with the limiting value for the experimental results. The decrease in $\Delta\epsilon/c$ at higher concentration is much larger than would be expected from the Clausius-Mosotti equation.

* Supported by the Chemical Corps Medical Laboratories.
[1] G. Birnbaum, Rev. Sci. Instr. **21**, 169 (1950).
[2] H. C. Thacher, Jr., J. Phys. Chem. **56**, 795 (1952).

H7. A Precision Double-Focusing Mass Spectrometer.* T. L. COLLINS, T. T. SCOLMAN, AND A. O. NIER, *University of Minnesota.*—A large double-focusing mass spectrometer has been constructed and is now operating. The machine utilizes a 90° electrostatic analyzer followed by a 60° magnetic analyzer with radii of 20 and 16 inches, respectively. The ion-optical design is similar to smaller spectrometers in use in this laboratory.[1] The electronic control system utilizes a small spectrometer with a modulated beam. A second major control system senses the position of the beam directly after the electrostatic analyzer in order to regulate the 35 kilovolt accelerating potential. Major mechanical features include object and image slits completely adjustable for position, width, and rotation through a single sylphon. The resolution exceeds 1 in 25 000.

* Supported by the National Science Foundation and the joint program of the U. S. Office of Naval Research and the U. S. Atomic Energy Commission.
[1] A. O. Nier and T. R. Roberts, Phys. Rev. **81**, 507 (1951).

H8. Electron Impact Studies of Isotopic Oxygen and Carbon Dioxide Molecules.* OLIVER A. SCHAEFFER AND HENRY R. OWEN, *Brookhaven National Laboratory.*—The relative changes in the probability of bond breaking following electron impact has been studied for the molecules $O^{16}O^{16}$ and $O^{16}O^{18}$; $O^{16}C^{12}O^{16}$, $O^{16}C^{13}O^{16}$, and $O^{16}C^{12}O^{18}$. The experimental results were obtained with a 60° mass spectrometer employing a source designed to equalize the collection efficiency of the fragment ions formed. The experimental results are compared with a calculation based on a "vertical" transition mechanism for the electron impact process. In the case of oxygen the experimental ratio of bond breaking in $O^{16}O^{16}$ divided by that in $O^{16}O^{18}$ was 0.98 compared to a calculated ratio of 0.97. The formation of C^{12+} from $C^{12}O_2^{16}$ was found to be 1.010 times larger than the formation of C^{12+} from $C^{12}O_2^{16}$; while the formation of $C^{12}O^{16+}$ was found to be 0.96 times as large as the formation of $C^{12}O^{16+}$ from the respective molecules. The calculated values for these two quantities are 1.013 and 0.98, respectively. Similar agreement was found for the processes in the $O^{16}C^{12}O^{18}$ molecule. The calculation adequately describes the electron impact process studied, even though for some processes fragmentation of the heavier molecule is predominant, while for other processes the fragmentation of the lighter molecule is predominant.

* Work performed under the auspices of the U. S. Atomic Energy Commission.

H9. The Law of Impact for Stiff Bodies. M. AVRAMY MELVIN, *Florida State University.*—The usual method of measuring the coefficient of restitution e with two pendular balls is not very accurate. Also it is not known (though generally assumed) that the approximate constancy of e, for a given material, will extend to noncentral collisions of two aspherical bodies. To test the constancy of e with accuracy, we made experiments with a pair of impacting Kater pendula with various mass distributions. The results (for steel) show that, with given unequal mass distributions, e may vary considerably from constancy (e.g., from 0.199 to 0.051) as the kinetic energy before impact E is varied. There is a tendency for the value of e to decrease with increasing value of E. The interpretation is discussed elsewhere. A practical inference which may be drawn from the present investigation is that f, the ratio of kinetic energy to that before impact, *is generally a better empirical constant than e.* For many materials e, though variable, is appreciably smaller than 1. In such cases f depends primarily upon the mass distribution and may be calculated therefrom while inserting a rough average value for e. f as measured stays very nearly constant for any given mass distribution and agrees very well with the calculated value.

H10. Some Aspects of the Dynamics of Waterdrop Collisions with Solids. OLIVE G. ENGEL, *National Bureau of Standards.*—Little information exists in regard to the stages of collision and flow of a water drop when it impinges against a solid surface. The radial flow in the impact plane was mapped chemically at the National Bureau of Standards and high-speed pictures of the collision incident have been made. Pictures taken at a rate of about 10 000 frames per second show that the water drop is very little deformed before it enters into radial flow. The top of the drop essentially appears not to know that the bottom has struck. An equation for the impact pressure has been developed which takes into account the spherical shape of the drop and its property of flow. Evidence exists which indicates that values of the pressure calculated from this equation are of the right order of magnitude. The diameter of the radial flow has been measured at known intervals of time. An equation for the radius of flow as a function of time has been developed on the assumption that the kinetic energy of the drop is converted to surface energy. Consideration has been given to the possible existence of cavitation in the radial flow. Schlieren pictures of the flow have been taken.

H11. Drop Size Distribution and Visibility in Clouds and Rain.* SHEPARD BARTNOFF, *Tufts College.*—The analysis of two sets of drop size distributions in natural clouds and one set of drop size distributions in rain indicates that the coefficient C in Trabert's visibility equation, $V = (C\rho\bar{r})/W$, is a function of the breadth of the distribution. In this equation, $\bar{r}$ is mean linear radius, ρ density, and W liquid water content.

As pointed out by Atlas and Bartnoff,[1] a more useful equation is found to be $V=(K\rho d_0)/W$, where d_0 is the median volume diameter. The usefulness of the Atlas and Bartnoff equation is supported by the present analysis, which verifies that the coefficient K is nearly independent of the breadth of the drop-size distribution and which indicates that the value $K=1.2$ found by Atlas and Bartnoff for natural clouds also holds for rain.

* This work is supported by a contract with the Air Force Cambridge Research Center.

[1] D. Atlas and S. Bartnoff, J. Meteorol. 10, 143–148 (1953).

H12. (Abstract withdrawn.)

H13. (Abstract withdrawn.)

H14. The JAINCOMP-C and -D Digital Computers. DONALD H. JACOBS AND MILTON E. PUGH, *The Jacobs Instrument Company.*—JAINCOMP-C is a very compact high speed electronic digital computer of the all-electronic all-parallel design developed in earlier JAINCOMP computers. Its addition time is 8 μsec, and it is capable of solving an equation involving 200 3-address operations (involving 9 continuous variables and 70 adjustable constants) in 0.1 sec. It was developed for real-time control use, and special input and output equipment was developed with it. Its program is contained on an electronically scanned punched card holding 128 24-bit instructions and having an access time of 1 microsecond per instruction. Adjustable constants are also stored on electronically scanned punched cards, and intermediate results are stored in JAINCOMP-type magnetic core registers having an access time of 3 μsec per word. Word length is 24 bits. Nine semimagnetic registers are provided as buffer storage for variable inputs. The entire computer, which is entirely of plug-in construction, fits in a cabinet $21\frac{7}{8}\times24\frac{1}{4}\times27\frac{3}{8}$ in. A completely automatic system of continuous functional checking is built in. JAINCOMP-D (designed but not constructed) is a general-purpose high-capacity version of JAINCOMP-C. Differences are (a) 36 bit words, (b) large memory: 1024 36-bit words of magnetic storage plus magnetic tape plus other types, and (c) much greater flexibility: can be controlled from punched card or magnetic tape or from memory, all interchangeable.

THURSDAY AFTERNOON AT 2:15

Sheraton Park, Burgundy Room

(M. H. HEBB presiding)

Nonmetallic Solids. II

I1. Growth of CdI_2 Crystals. J. B. NEWKIRK, *General Electric Research Laboratory* (introduced by D. Turnbull).—An experimental study of CdI_2 crystals growing in aqueous solution gave evidence which supports hypotheses of Fisher, Fullman, and Sears concerning the origin of growth steps on crystal surfaces. Self-perpetuating growth steps were observed to form spontaneously on the hexagonal face of an apparently perfect crystal which was growing in the edgewise direction only. As proposed by the above authors, this could result from disregistry of lattice planes where they meet after growing around a dirt particle that had been trapped by the advancing edge of the crystal. Spiral growth steps also formed at the point of contact where two randomly oriented crystals meet edge to edge. Motion pictures are presented which illustrate the above effects.

I2. The Influence of Covalence on Ion Ordering and Distortion in Spinels. I.* A. L. LOEB AND J. B. GOODENOUGH, *Lincoln Laboratory.*—In previous attempts to explain the cation distribution in spinel lattices on the basis of elastic and electrostatic energies, covalence was resorted to in order to account for the preference of certain cations for tetrahedral sites. A later treatment, based on the perturbation of *d*-shells by a crystalline field due to surrounding ions, is limited by the assumption of ionic lattice elements. A mechanism based on covalent bonding due to overlap of hybrid orbitals is proposed here to predict the cation distribution and related properties of spinels. Cations in tetrahedral sites usually bond through tetrahedral sp^3 orbitals; in octahedral sites cations are bound ionically, or covalently through either octahedral d^2sp^3 or planar dsp^2 bonds. In the last case the cation is bound covalently to four oxygen ions at the corners of a square, and ionically to two oxygen ions on an axis normal to the square, so that tetragonal distortion of the lattice results. Covalence decreases the electrostatic and modifies the elastic energies. A covalent exchange mechanism is proposed for the indirect interaction between incomplete *d* shells.

* The research reported in this and the following abstract was supported jointly by the U. S. Army, the U. S. Navy, and the U. S. Air Force under contract with the Massachusetts Institute of Technology.

I3. Measurement of the Elastic Constants of Cobalt and of Cobalt Zinc Ferrite Crystals. H. J. MCSKIMIN, A. J. WILLIAMS, AND R. M. BOZORTH, *Bell Telephone Laboratories.*—The 5 elastic constants of hexagonal cobalt have been determined using pulse modulated ultrasonic waves which are reflected back and forth within the crystal. Frequencies between 15 and 30 Mc/sec were used. Values of the constants were derived from 11 measurements of wave velocities for longitudinal and shear modes in 3 crystals, using a phase comparison technique. At 25°C the constants (all in 10^{12} dynes/cm^2) are: $c_{11}=3.071\pm0.5$ percent, $c_{12}=1.650\pm0.5$ per-

cent, $c_{13}=1.027\pm1.5$ percent, $c_{33}=3.581\pm0.5$ percent, $c_{44}=0.755\pm0.5$ percent. These are based on a density of 8.836. The volume compressibility is calculated to be 0.526×10^{-12} cm²/dyne, a value close to that obtained by extrapolating Bridgman's 1949 results to zero pressure. Similar measurements for cubic cobalt zinc ferrite ($Co_{0.32}Zn_{0.22}Fe_{2.2}O_4$) give at 30°C (in 10^{12} dynes/cm²): $c_{11}=2.66$, $c_{12}=1.53$, $c_{44}=0.78$, based on density 5.43.

I4. The Equation of State and the Thermal Dependence of the Elastic Coefficients of Crystalline Argon. JOHN H. HENKEL, *Brown University* (introduced by R. B. Lindsay).—An interaction potential of the form $(A/R^{10})-(B/R^6)$ for two argon atoms is assumed. The values of A and B are evaluated using the heat of sublimation and the lattice constant at temperature $T=0$°K and pressure $p=0$. By assuming that each atom moves in a potential field due to all the other atoms at rest in their mean positions a theory is developed for anharmonic vibrations using the perturbation theory for a harmonic oscillator. The partition function for each argon atom is obtained and the equation of state is calculated. The specific heat equation obtained represents a correction to the Einstein form. The specific heats at constant pressure are calculated as a function of temperature and deviate from the experimental ones by only 3 percent at low temperatures (15°K–30°K) and only 1 percent at higher temperatures. The isothermal elastic coefficients C_{11}, C_{12}, and C_{44} are calculated by Born's method without neglecting the part played by the thermal energy. The Cauchy relation is found to be invalid, C_{44} being about twice C_{12} at the higher temperatures.

I5. Vibration Spectra of Crystal Lattices. MELVIN LAX AND JOEL L. LEBOWITZ, *Syracuse University*.—The frequency distribution $g(v)$ of a crystal is approximated by combining Van Hove's[1] determination of the analytical nature of $g(v)$, and Montroll's method of moments.[2] The function $g(v)$ is represented by an expression with the correct behavior at the singularities and at the maximum and minimum frequencies. The behavior between singular points is adjusted smoothly by leaving n undetermined parameters. These parameters are then fixed by using the correct first n moments. As a test, this procedure was applied to the two dimensional square lattice with nearest and next nearest neighbor interactions, solved exactly for a particular case by Montroll.[3] The assumed distribution function had the right form at the end points, contained terms of the appropriate logarithmic form and a jump function (with known coefficients). It also included Legendre polynomials with unknown coefficients, which were determined by the moments. The difference between the exact and approximate distribution functions was a few percent using only the zeroth moment (normalization). Using higher moments produced a gradual increase in accuracy.

[1] L. Van Hove, Phys. Rev. **89**, 1189 (1953).
[2] E. W. Montroll, J. Chem. Phys. **10**, 218 (1942).
[3] E. W. Montroll, J. Chem. Phys. **15**, 575 (1947).

I6. Solid Surface Studies by Total Reflection of X-Rays.* L. G. PARRATT, *Cornell University*.—Analysis of the shape of the curve of reflected x-ray intensity *vs* glancing angle in the region of total reflection provides a method of studying certain structural properties of the mirror surface about 10 to a few hundred Angstroms deep. The theory, extended to treat any (small) number of stratified homogeneous media, is used as a basis of comparison. Curves for evaporated copper on glass are studied as an example. These curves probably can be explained by assuming that the copper (exposed to atmospheric air at room temperature) has completely oxidized about 150A deep. If oxidation is less than about 100A deep, there probably exists an electron density minimum just below an internal oxide seal. This seal, perhaps 50A below the nominal surface plane, arrests further oxidation of more deeply-embedded loose-packed copper crystallites. All measurements to date have been carried out under laboratory atmospheric conditions which do not allow satisfactory separation or control of the physical and chemical variables involved. Under better control, the method seems promising.

* This research was supported by the U. S. Air Force through the Office of Scientific Research of the Air Research and Development Command.

I7. Equipment for the Measurement of Very Small X-Ray Scattering Cross Sections.* W. W. BEEMAN AND R. H. NEYNABER, *University of Wisconsin*.—A rotating anode, water-cooled, x-ray tube, vacuum-scattering chamber, and proportional counter detector will be described. With slits furnishing an angular resolution of ±14 minutes, a copper anode, and 30 Kv and 100 ma on the tube, over 10^9 effective (i.e., taking into account window absorption and counter efficiency) CuKα photons per second illuminate the scattering sample. Background counting rates, with the sample removed, are one-half count per second. Absolute scattering cross sections are measured by calibrating the geometry at small angles with a gas scatterer. Under the above conditions of operation a two centimeter path of air at STP furnishes over 120 counts per second. Angular measurements may be made from a lower limit determined by the slit resolution (about 1 degree scattering angle with the above slits) up to 110°. Possible applications include the measurement of scattering from gases, liquids and imperfect lattices away from Bragg angles. With a scattering sample of cold worked nickel and an iron anode we have verified the small-angle vacancy scattering first reported by Blin and Guinier. Counting rates are about 20 counts per second.

* Research supported by the Wisconsin Alumni Research Foundation, the U. S. Office of Naval Research and the U. S. Office of Scientific Research, Air Research and Development Command.

I8. Propagation of Displacement in a Solid, Having a Crystalline Structure with Bistable States.* C. F. PULVARI, *The Catholic University of America*.—Displacement in function of field and temperature has been extensively treated in bistable crystalline solids such as $BaTiO_3$. This paper offers a theory for displacement in function of field and duration of acting field. A continuous bistable potential barrier has an unstable intermediate state. Such a barrier can be represented by a function $\varphi(\eta, U)$ being a fourth-order polynomial of η where U denotes the activation energy as a parameter, and η the displacement vector. The equation of displacement is given by $m(d^2\eta/dt^2)=(\partial\varphi/\partial\eta)$, where m is the mass of the displaced particle. From the results the onset of unelastic displacement and the propagation of polarization is obtained.

* This work is supported by a U. S. Air Force Contract.

I9. Granular Structure of Barium Titanate Ceramic.* JOHN L. SAMPSON, EDWARD E. ALTSHULER, AND CHARLES R. MINGINS, *Tufts College*.—The granular structure of barium titanate in polycrystalline ceramic form has been investigated using the electron microscope. It is found that the grain size is considerably different at a fired surface from what it is in the interior, so that an estimate of scattering or diffusion of energy in a piece of ribbon would be in error if the grain size observed at the surface were used. Very small regular striae are sometimes found; they may be associated with lattice vibrations at phase transition. "Natural" surfaces have been compared with etched surfaces and with surfaces which have been worked in various ways. Observations have also been made on grown crystals.

* Part of an investigation sponsored by the U. S. Army Ordnance Corps.

I10. On Counting Lattice Frequencies. HERBERT B. ROSENSTOCK, *U. S. Naval Research Laboratory*.—Van Hove[1] has traced the singularities[2] in the frequency spectra of

crystals to the "critical points" (points where all $\partial\omega^2/\partial k_i$ vanish) of the frequency in wave number space, and shown that the periodicity of a 3-dimensional crystal alone implies the existence of at least 8 critical points. Whenever ω^2 may be written as a function of the $c_i=\cos k_i$ alone, it follows that 8 critical points are located at the corners of the half-periodicity cube. Others may be found by studying $\omega^2(c)$ on the edges and surfaces of the cube, where the secular determinant simplifies greatly; the behavior inside may be inferred with little ambiguity from that on the surfaces by simple topological considerations. Though the "shape" of the frequency distribution is thus determined, its absolute value anywhere is not. For this, Montroll's approximate method,[3] when modified to take account of the singularities, appears to give adequate results without excessive labor. Preliminary results for the simple, f.-c., and b.-c. cubic lattice will be given.

[1] L. Van Hove, Phys. Rev. **89**, 1189 (1953).
[2] See H. B. Rosenstock and G. F. Newell, J. Chem. Phys. **21**, 1607 (1953) and references therein.
[3] E. W. Montroll, J. Chem. Phys. **10**, 218 (1942); J. Chem. Phys. **11**, 481 (1943).

I11. Calculation of Electrostatic Lattice Potentials, Including Ionic Overlap. JOSEPH BIRMAN, *Sylvania Electric Products, Inc.*—It is necessary to know the electrostatic lattice potential at some point r in an ionic crystal in order to calculate electronic energy levels at a vacancy, activation energy for ionic diffusion, and similar quantities. The conventional method of calculation, due to Ewald,[1] proceeds by shrinking the ions down to point singularities whose charge equals the net charge of the ion. It will be shown how a slight modification of Ewald's method enables one to calculate the lattice potentials in a more realistic lattice, namely one where the ions are represented as point positive cores (nucleus plus tightly bound inner electrons), surrounded by a Gaussian valence electron density. This valence electron density is normalized to give the ion its correct net charge, the half-width chosen in one of a number of ways, depending on the accuracy desired. The effect of increasing the half-width (and therefore the overlap) of the ions will be illustrated by showing the effect of overlap on the self-potential (Madelung Constant) of an NaCl structure.

[1] M. Born and M. G. Mayer, *Handbuch der Physik 24/2* (Julius Springer, Berlin, 1933), p. 711.

I12. Thermal Ionization of Impurities in Polar Crystals. H. D. VASILEFF, *Sylvania Electric Products, Inc.*—A general expression for the thermal ionization rate of an impurity in a polar crystal has been derived. The interaction energy of the trapped electron with the optical vibrational modes was assumed to be linear in the normal vibrational coordinates of the lattice. The eigenvalue equations and perturbation of the Born-Oppenheimer adiabatic potential method were employed. The method of O'Rourke[1] was applied, giving a result in agreement with that of Huang and Rhys.[2] It was found that a multiphonon transition is due fundamentally to a nonzero value of the configurational constant S. A simplified expression for the rate can be obtained only for very low temperatures.

[1] R. C. O'Rourke, Phys. Rev. **91**, 265 (1953).
[2] K. Huang and A. Rhys, Proc. Roy. Soc. (London) **A204**, 406 (1950).

THURSDAY AFTERNOON AT 2:15

Sheraton Park, Caribar Room

(JOHN TINLOT presiding)

Theoretical Physics, II: High-Energy Scattering

IA1. Internal Pair Production in the Radiative Absorption of π^- Mesons by Hydrogen Atoms. W. WADA, *Naval Research Laboratory.*—Using the standard field theoretical method the internal pair-production coefficient for the radiative absorption of slow π^- mesons by hydrogen atoms has been calculated. The probability per second that the pair production takes place, as a function of the emergent neutron energy, is found to have a sharp maximum in the close vicinity of the maximum neutron kinetic energy (9.2 Mev). The ratio of the total probability for the pair production to the radiative absorption probability is found to be of the order of magnitude of the fine structure constant in agreement with experiment.[1] Although a pseudoscalar meson field with a pseudoscalar coupling is employed for our calculation, a pseudovector coupling is also expected to give a similar ratio by virtue of the equivalence theorem. The distribution of angles between pairs is being calculated at the energy of the neutron for which the pair production probability is maximum and will be presented.

[1] Sargent, Rinehart, Cornelius, Lederman, and Rogers, Bull. Amer. Phys. Soc. **28**, No. 6, 13 (1953).

IA2. Approximate Equations for Meson-Nucleon Systems. RICHARD ARNOWITT AND S. GASIOROWICZ, *University of California, Berkeley.*—The scattering and production Green's functions for one nucleon and an arbitrary number of mesons are related by an infinite set of coupled linear integral equations. The first N of these equations contain Green's functions involving 0, 1, 2, $\cdots$ N external meson lines. Experimentally no closely bound states of one nucleon with a large number of real mesons appear to exist. This suggests the approximation of factoring the Green's function with N external meson lines into products of lower Green's functions, as recently proposed by M. Neuman. In particular one may do this by breaking off a single meson propagation function in a symmetric fashion. If vacuum polarization effects are neglected, the resulting equations remain linear. Taking $N=1$ leads to the lowest order perturbation result. $N=2$, which involves the breakup of the meson-nucleon Green's function (i.e., neglecting the meson-nucleon interaction) leads to the S_F' function of Brueckner, Gell-Mann, and Goldberger. Taking $N=3$ means ignoring meson production in meson-nucleon scattering, etc. In the last case an integral equation involving only the meson-nucleon kernel may be derived. Approximate solutions will be discussed. This work was performed under the auspices of the U. S. Atomic Energy Commission.

IA3. Meson Production in Meson-Proton Scattering. M. S. NELKIN* AND H. A. BETHE, *Cornell University.*—The integral equation for meson-nucleon scattering in the lowest Tamm-Dancoff approximation[1] is considered for $E>M+2\mu$. If the two meson, one nucleon energy denominator in the kernel is evaluated as a δ_+ function, then the Goldberger[2] scattering amplitude evaluated on the energy shell gives the tangent of

the complex phase shift. If the imaginary part of the phase shift is small, then the imaginary part of the integral equation can be reduced to a form identical to the real part except for the behavior of the inhomogeneous term at small momenta. If this difference is ignored, the ratio σ(production)/σ(scattering) can be calculated without solving the integral equation, and turns out to be less than 1 percent at 400 Mev. Numerical results will be given, and the validity of the approximations used examined.

* National Science Foundation predoctoral fellow.
[1] Dyson, Schweber, and Visscher, Phys. Rev. **90**, 372(A) (1953).
[2] M. L. Goldberger, Phys. Rev. **84**, 929 (1951).

IA4. Meson-Meson Effects in Meson Nucleon Scattering. MARC H. ROSS, *Brookhaven National Laboratory.**—Experimental information is becoming available at present which enables a phenomenological test of the suggestion that meson-meson interaction plays an important role in meson nucleon scattering. We assume that the interaction (a) between the incoming meson and the nucleon's proper field, can be represented by a potential, common to all angular momenta, of long range, i.e., of order meson compton wave length; and that the direct meson nucleon interaction (b) is of short range. In addition to phase shifts obtained directly from scattering differential cross sections, we consider indirect phase shift information from various near zero energy experiments and from comparison of meson photoproduction with scattering at all energies. The present data suffice only to determine the shallow attractive well for (a) with $T=\frac{3}{2}$. A specific prediction providing a test of the model is attractive D wave phase shifts (for $T=\frac{3}{2}$) around 250 Mev of magnitude considerably larger than one might expect from (b) alone. Of greater significance at present are general implications of the problem: (1) It seems quite possible that a separation of effects (a) and (b) exists. Thus continued and improved low-energy scattering experiments are of great interest. (2) Great caution should be exercised in comparing a meson theoretical calculation of (b) alone with experimental results.

* Work done under the auspices of the U. S. Atomic Energy Commission.

IA5. Pion-Nucleon S Phase Shifts at Low Energy.* H. P. NOYES, *University of Rochester.*—Bernardini *et al.* have shown[1,2] that their recent results on the photoproduction of charged pions in hydrogen and deuterium near threshold, combined by detailed balancing with Panofsky's results for the absorption of π^- mesons in hydrogen, give $\alpha_1-\alpha_3=0.16p/\mu c$ $(1^+-0.25)$, where α_1 and α_3 are the S phase shifts of isotopic spin $\frac{1}{2}$ and $\frac{3}{2}$, respectively. This is in clear contradiction with the value obtained by *linear* extrapolation from the results of the pion scattering experiments at Columbia at 65 Mev and at Rochester at 40 Mev,[1] which is $0.33p/\mu c$. It is, however, explicable in terms of the S wave potential model proposed by Marshak as extended by Woodruff, which gives $0.2p/\mu c$, using the following parameters: $I=\frac{1}{2}$; $V=V_0\exp(-r/r_0)$; $V_0=-105$ Mev; $r_0=0.65\times10^{-13}$ cm. $I=\frac{3}{2}$; $V=+\infty$, $r\leq r_c$ $=0.54\times10^{-13}$ cm; $V=V_0\exp-(r-r_c)/r_0$, $r>r_c$; $V_0=-187$ Mev; $r_0=0.60\times10^{-13}$ cm. A least squares analysis of the 40 Mev pion-nucleon scattering data will be presented and the resulting limitations on the values of the phase shifts and the parameters of the model will be discussed.

* Supported by the U. S. Atomic Energy Commission.
[1] *Proceedings of the Fourth Annual Rochester Conference*, University of Rochester, Physics Department, 1954.
[2] Bull. Am. Phys. Soc. **29**, No. 1, G4 (1954).

IA6. Electron Scattering from Nuclei. G. T. TRAMMELL, *Oak Ridge National Laboratory.*—To aid in the theoretical evaluation of the high-energy electron-heavy nucleus elastic scattering experiments of Hofstadter and collaborators,[1] the Oak Ridge electronic digital computer (ORACLE) is being used for the calculation of the scattering cross sections from several assumed nuclear charge distributions. The results obtained will be presented.

[1] Hofstadter, Fechter, and McIntyre, Phys. Rev. **92**, 978 (1953).

IA7. High-Energy Electron Scattering. J. MAYO GREENBERG, *Rensselaer Polytechnic Institute.*—An investigation of nucleonic distribution in the nucleus by scattering of electrons whose wavelength is sufficiently small to demonstrate some structural detail is being conducted by Hofstadter and coworkers at Stanford University. The analysis of the experimental results is hampered by the fact that it is necessary to perform tedious phase shift calculations for various trial models of the nucleus. The scattering approximation of Montroll and Greenberg[1] seems particularly suitable to the high-energy electron scattering problem. Calculations which are essentially based on an application of this method using the Dirac equation are presented and compared with exact results of Yennie *et al.*, using phase shift analysis.

[1] E. W. Montroll and J. M. Greenberg, Phys. Rev. **86**, 889 (1952).

IA8. Coulomb Energy and Nuclear Radius. B. JANCOVICI, *Princeton University* (introduced by E. P. Wigner).—The discrepancy between the values $(1.45\times10^{-13}A^{\frac{1}{3}}$ cm) for the nuclear radii derived from mirror nuclei and those $(1.2\times10^{-13}A^{\frac{1}{3}}$ cm) derived from μ-mesonic atoms was investigated. The calculation was based on the shell model with a square well potential, the depth of which was adjusted to fit the experimental binding energy of the last nucleon. The radius of the well was chosen to fit the mesonic atom data. These depend on the mean square radius of the total charge distribution. The Coulomb energy difference ΔE_c of the β transition was computed, including exchange terms. ΔE_c can be expressed in terms of r_c defined by $\Delta E_c=1.2Ze^2/(r_c10^{-13}A^{\frac{1}{3}}$ cm). For (O^{15},N^{15}) the computed r_c is 1.29, the experimental value 1.41. In F^{17}, the last proton is outside the closed shells and, hence, loosely bound. The computed ΔE_c is smaller and gives r_c $=1.37$; however, the experimental r_c is 1.52 in this case. Therefore, the experimental discontinuity in r_c at the closure of the p shell is reproduced by the model but the computed absolute values of r_c remain too small.

IA9. Interpretation of Scattering of High-Energy Nucleons by Complex Nuclei.* I. I. SHAPIRO AND J. M. TEEM,† *Harvard University.*—The Glauber[1] procedure has been used to calculate angular distributions of protons scattered elastically from C and Al at 96 Mev. Comparison with recent experimental results[2] has been made. The Coulomb potential for a uniformly charged nucleus was used, combined with a complex square well of width $r_0A^{\frac{1}{3}}+r_1$, the first term representing the electromagnetic radius and the second the extension of size due to nuclear forces. The well parameters were taken to be those for neutron scattering. They were obtained by a "best fit" of energy dependent total cross sections, known absorption cross sections, and elastic cross sections at 84 Mev. The well depths, assumed independent of A, have variations with energy similar to Taylor's.[3] Investigations of neutron scattering using other potential forms, e.g., Gaussian, to determine edge effects of the square well, will also be discussed.

* Assisted by the joint program of the U. S. Office of Naval Research and the U. S. Atomic Energy Commission.
† National Science Foundation Predoctoral Fellow.
[1] R. J. Glauber, Phys. Rev. **91**, 459 (1953).
[2] K. Strauch and F. Titus, Bull. Am. Phys. Soc. **29**, No. 1 (1954), abstract T6.
[3] T. B. Taylor, Phys. Rev. **92**, 831 (1953).

IA10. Nuclear Cross Sections and the Size of the Nucleus.* WARREN HECKROTTE, *University of California, Berkeley.*—The experiments of Millburn *et al.* at this laboratory on the determination of the inelastic nuclear cross sections for high-energy deuterons yield the following expression for the cross

section as a function of the mass number of the target nuclei: $\sigma=\pi(1.68A^{\frac{1}{3}}+0.64)^2\times10^{-26}$ cm². It may readily be shown that this implies the value $R=1.68\times A^{\frac{1}{3}}\times10^{-13}$ cm for the nuclear radius and $R_D=2.56\times10^{-13}$ cm for the mean separation of the particles in the deuteron. To understand further this result for the nuclear radius, the total nuclear cross sections for 90-Mev neutrons have been interpreted in terms of a non-square well nuclear density distribution. Taking for numerical simplicity a parabolic shape, the radius (measured to the edge of the distribution) that is obtained is $R=1.60\times A^{\frac{1}{3}}\times10^{-13}$ cm. The significance of this result and the experimental result as compared with other determinations of the nuclear radius will be discussed.

* This work was performed under the auspices of the Atomic Energy Commission.

IA11. Nuclear Radii and Transparencies from Inelastic Cross-Section Measurements. I. Method.* G. P. MILLBURN, *University of California, Berkeley,* AND W. BIRNBAUM, W. E. CRANDALL, AND L. SCHECTER, *California Research and Development Company.*—The total inelastic cross sections for high-energy protons, deuterons, He^3 particles, and alpha particles accelerated in the 184-inch cyclotron were measured by an attenuation technique. Integral range curves for various absorbers were measured and analyzed to account for the secondary charged particles present in the beam of attenuated particles. A relation between the inelastic cross sections of protons and deuterons permits a straightforward analysis of the curves for deuterons and yields the stripping cross sections. Corrections for multiple scattering and true path length in the absorber were applied to the data.

* Supported by the U. S. Atomic Energy Commission.

IA12. Nuclear Radii and Transparencies from Inelastic Cross-Section Measurements. II. Interpretation.* W. E. CRANDALL, W. BIRNBAUM, AND L. SCHECTER, *California Research and Development Company,* AND G. P. MILLBURN, *University of California, Berkeley.*—The inelastic cross sections for multi-nucleon bombarding particles fit a relation, $\sigma_n=\pi(a_nA^{\frac{1}{3}}+R_n)^2$, where a_n and R_n depend upon the bombarding particle. To obtain an expression in which the nuclear radius appears explicitly, further simplifying assumptions are introduced for loosely bound multi-nucleon system, such as deuterons and He^3 particles, allowing the inelastic cross section to be expressed in the form, $\sigma_n=\pi(a_0A^{\frac{1}{3}}+R_n)^2(1-\tau^n)$, where $a_0A^{\frac{1}{3}}$ may be interpreted as the radius of the struck nucleus, including a highly transparent fringe region, and τ is the average transparency of this nucleus to the individual nucleons of the bombarding nucleus.

* Supported by the U. S. Atomic Energy Commission.

IA13. Polarization in Scattering by Nuclei at High Energies.* B. J. MALENKA, *Harvard University.*—Recent experiments indicate a considerable polarization in high-energy proton scattering by the larger nuclei. It is suggested that this effect can be principally explained by assuming a simple spin-orbit interaction of the form and magnitude required in the theory of shell structure. An initial approach to this problem is carried out by treating the spin interaction term in Born approximation. A more accurate approximation is obtained if we note that the polarization effect has been observed at comparatively small scattering angles. This permits us to treat the scattering problem with polarization by making use of a technique introduced by Glauber[1] which effectively sums the complete Born series for high-energy and small-angle potential scattering. A rough preliminary calculation appears to indicate that the maximum polarization occurs for an appropriate range of scattering angle.

* Partially supported by the joint program of the U. S. Office of Nava Research and the U. S. Atomic Energy Commission.

[1] R. J. Glauber, Phys. Rev. **91**, 459 (1953).

IA14. Polarization Effects in High-Energy Proton-Deuteron Scattering. S. TAMOR, *University of California, Berkeley.*—Recent experiments on the polarization of high-energy protons scattered from light elements[1,2] (Be, C) indicate considerably larger effects than those obtained in *p-p* and *n-p* scattering.[1-3] Since calculations[4,5] of polarization in *p-p* and *n-p* scattering using tensor interactions give reasonable agreement with experiment it is interesting to investigate whether the polarization from more complex nuclei can be described in terms of the same nucleon-nucleon forces with inclusion of interference and spin-correlation effects. Using a formalism already described,[6] calculations have been carried out on the polarization produced in elastic proton-deuteron scattering at 240 Mev. A significant enhancement of the polarization is obtained, especially at larger angles. A detailed discussion of results will be presented. This work was performed under the auspices of the U. S. Atomic Energy Commission.

[1] C. L. Oxley *et al.*, Phys. Rev. **91**, 419 (1953).
[2] O. Chamberlain *et al.*, Phys. Rev. (to be published).
[3] L. F. Wouters, Phys. Rev. **84**, 1069 (1951).
[4] D. R. Swanson, Phys. Rev. **89**, 749 (1953).
[5] L. J. B. Goldfarb and D. Feldman, Phys. Rev. **88**, 1099 (1952).
[6] S. Tamor, Phys. Rev. **93**, 227 (1954).

FRIDAY MORNING AT 9:30

NBS, East Building

(R. T. BIRGE presiding)

Invited Papers in Electron Physics

J1. Survey of Characteristic Energy Losses of Electrons. L. MARTON, *National Bureau of Standards.* (30 min.)

J2. Electron Interaction in Solids. DAVID PINES, *University of Illinois.* (30 min.)

J3. Some Fundamental Processes of Gaseous Electronics. L. B. LOEB, *University of California, Berkeley.* (40 min.)

J4. Buildup Processes in Sparks and Positive Corona. L. H. FISHER, *New York University.* (30 min.)

FRIDAY MORNING AT 9:30

Sheraton Park, Burgundy Room

(W. W. WATSON presiding)

Spectra from X-Rays through Microwaves

JA1. *K*-Absorption Edge Studies of Compounds. H. P. HANSON, *University of Texas*, AND J. R. KNIGHT, *University of Florida*.—A series of *K*-absorption edge curves have been obtained for various compounds of the elements $Z=25$ through $Z=30$. The fluorides, chlorides, oxides and sulfides of these metals were investigated. The significant trends which were observed in the data will be discussed in terms of the homopolar nature of the bonding and the decreasing number of vacancies in the *d* shell.

JA2. X-Ray Absorption in Solid Argon.* JACK SOULES† AND C. H. SHAW, *The Ohio State University*.—The structure of the argon *K*-absorption edge at 3.86A has been investigated under high resolving power using the two crystal x-ray spectrometer with calcite crystals. Solid argon films of controllable thickness were prepared by freezing the gas onto a Beryllium window backed by liquid helium. A proportional counter detector and pulse height analyzer permitted the use of high x-ray tube voltage without the confusion of second order effects. Data were obtained for argon in both the gaseous and solid states. Previous work[1] on the gas absorption is confirmed and extended to interpret the electron band structure of the solid.

* Supported by the U. S. Office of Naval Research.
† DuPont Fellow, 1952–53.
[1] L. G. Parratt, Phys. Rev. **56**, 295 (1939).

JA3. *L*-Absorption Spectrum of Silicon and Silicon Dioxide.* D. E. BEDO AND D. H. TOMBOULIAN, *Cornell University*.—Following a method described previously,[1] absorption measurements have been carried out in the spectral region extending from 60A to 200A. Absorbers were prepared by evaporation on a glass substrate treated with "Victo-wet." Deposited films sprayed with Zapon were floated off and suitably mounted. Preliminary measurements on Si show a repeatable absorption edge at 124.5A to be identified with the $L_{2,3}$ discontinuity. A similar edge appears in the case of SiO_2, but its position is shifted towards shorter wavelengths by 8A. No measurements have been reported on the absorption by the semiconductor or its dioxide in the soft x-ray region. However, a similar shift in the edge is revealed in a study[2] of the *K*-absorption spectrum of Si and SiO_2. In conjunction with the available information on the *L*-emission band of Si, the present measurements lead to the value of 0.8 ev as an estimation of the energy gap in the semiconductor.

* Supported by the Office of Ordnance Research, U. S. Army.
[1] D. H. Tomboulian and E. M. Pell, Phys. Rev. **83**, 1196 (1951).
[2] V. P. Barton and G. A. Lindsay, Phys. Rev. **71**, 406 (1947).

JA4. An Extension of the Extreme Ultraviolet Solar Spectrum. F. S. JOHNSON, J. D. PURCELL, AND R. TOUSEY, *Naval Research Laboratory*.—New spectra of the sun were obtained on February 2, 1954 from a rocket between 80 and 104 km altitude. All ten exposures show the Lyman alpha line of hydrogen (1216A) in emission and several are greatly overexposed. The continuum was photographed to 1750A. The Schumann-Runge bands of oxygen appear in the continuum with intensity depending on altitude. On the highest exposure traces of the continuum can be seen between 1100 and 1300A at the wavelengths of the O_2 transmission windows. Except for this, the continuum below 1750A was entirely absorbed by the O_2 present above 104 km. The spectrograph was kept directed at the sun by means of the pointing control developed and constructed by the University of Colorado[1] and made available by the U. S. Air Force. Fog due to stray light was reduced, so as not to swamp the extreme ultraviolet, by using a plastic grating, made by removing the aluminum from a Bausch and Lomb replica, and by focusing the sun on the slit with a mirror of quartz whose reflectance increases below 2000A, reaching a maximum[2] of approximately 20 percent near 1200A.

[1] Stacey, Stith, Nidey, and Pietenpol, Electronics **27**, 149 (1954).
[2] R. Tousey, Phys. Rev. **57**, 1060 (1940).

JA5. Pressure Shift in Helium λ5875.* JOHN R. HOLMES AND LEON PAPE, *University of Southern California*.—Using a Fabry-Perot interferometer, pressure shift in λ5875($2\,^3P - 3\,^3D$) of He^4 was looked for over a pressure range from 5×10^{-2} to 20 mm in a helium atmosphere. A mean shift of 0.0074 cm^{-1} toward lower frequency at the higher pressure was found. As this is within the experimental error it is concluded that over the above pressure range pressure shift is not likely to falsify significantly isotope shift measurements in the helium spectrum, in disagreement with Fred, Tomkins, Brody, and Hamermesh.[1]

* Supported partly by the U. S. Office of Naval Research.
[1] Fred, Tomkins, Brody, and Hamermesh, Phys. Rev. **82**, 406 (1951).

JA6. Spectroscopic Isotope Shift in Hf I and Hf II. J. A. COLLINSON AND W. W. WATSON, *Yale University*.—We have observed the hyperfine structure of some 70 Hf I and 20 Hf II lines in the range 2870–4900A. This structure is in every case either a line which appears single or a doublet (roughly 0.030–0.050 K) whose components are of the proper relative intensities to be produced by isotopes 178 and 180. The doublets are sometimes in the "negative" sense. In Hf I, the shifts are consistent with the tentative analysis of that spectrum[1] and indicate that the same electron configuration, presumably $5d^26s^2$ of the ground state, is responsible for all seven of the low-energy levels. Rasmussen[2] reported λλ 4837 and 4800 as single and λ 4655 as split, while we find λ 4837 double. In Hf II,[3] the double electron transition of λ 3134.72 ($5d6s^2\,^2D_{2\frac{1}{2}}$—$5d^26p\,^4G_{2\frac{1}{2}}$) exhibits structure substantially larger than that in any other line.

[1] W. F. Meggers and B. F. Scribner, J. Research Natl. Bur. Standards **4**, 169 (1930).
[2] E. Rasmussen, Naturwiss. **23**, 69 (1935).
[3] W. F. Meggers and B. F. Scribner, J. Research Natl. Bur. Standards **13**, 625 (1934).

JA7. Isotope Shift in the Li I Spectrum. RAYMOND H. HUGHES, *University of Wisconsin*.*—The previous work[1] on the isotope shift in the spectrum of the neutral lithium atom, in which the $2S-2P$ and $2P-3D$ transitions were studied in the hollow cathode spectra from separate isotopes[2] with the aid of a Fabry-Perot interferometer, has been extended to

TABLE I.

	$n=2$	3	4	5
$ns\,^2S_{1/2}$	$+0.037\pm0.007$	$+0.010\pm0.005$	$+0.003\pm0.005$	
$np\,^2P_{1/2,3/2}$	-0.119 ± 0.003			
$nd\,^2D_{3/2,5/2}$		$+0.002\pm0.006$	$+0.000\pm0.003$[a]	0.000 ± 0.003[a]

[a] Basis for assignment of the $2P$ shift.

include the transitions between the $2P$ and the $3S$, $4S$, $4D$, $5D$ levels. The specific shifts (i.e., the residuals after correcting for the normal reduced mass effect) have been determined with respect to the limit Li II $1s^2\ {}^1S_0$ as a reference point, and are listed in Table I. The + sign means that the corrected Li^7 level lies farther below $^1S_0$ than the Li^6. The errors shown are limit errors. Meissner's values for the $3D$, $4D$, and $5D$ doublet separations have been confirmed.[3]

* Supported partly by Office of Ordnance Research, U. S. Army.
[1] Raymond H. Hughes, Phys. Rev. **91**, 457(A) (1953).
[2] Obtained on loan from the Y-12 plant, Oak Ridge National Laboratory on U. S. Atomic Energy Commission allocation.
[3] Meissner, Mundie, and Stelson, Phys. Rev. **74**, 932 (1948).

JA8. The Vibrational Spectrum of Fluorotrichloroethylene.* D. E. Mann and Earle K. Plyler, *National Bureau of Standards.*—The infrared spectrum of gaseous $FClC:CCl_2$ has been observed in the range 3–50 microns. The Raman spectrum of the liquid has also been obtained. A complete and satisfactory vibrational assignment has been achieved. The planar fundamentals occur at 1645, 1181, 988, 857, 520, 407, 250, 174, and 144 cm^{-1}; the out-of-plane vibrations appear at 537, 358, and 123 cm^{-1}. Thermodynamic functions have been calculated.

* This work has been supported in part by the U. S. Office of Naval Research.

JA9. Microwave and Far Infrared Atmospheric Water-Vapor Absorption. T. F. Rogers, *Air Force Cambridge Research Center.*—Recent measurements and analyses[1] of rotation-vibration water vapor absorption bands have provided term values from which more accurate and extended calculations of long wavelength rotational transitions can be made.[2] Peak intensities of all predicted H_2O lines from 0–60 cm^{-1} and HDO from 0–35 cm^{-1} have been obtained for a 1 percent vapor concentration in air at 760 mm and 293°. The Van Vleck-Weisskopf modified Lorentz equation has been employed to calculate the complete absorption spectrum to 35 cm^{-1} for H_2O and 15 cm^{-1} for HDO. For the 0–15 cm^{-1} region, the H_2O absorption spectrum has further been calculated for several heights well into the troposphere thereby allowing estimates of total vertical absorption to be made.

[1] Benedict, Claasen, and Shaw, J. Research Natl. Bur. Standards **49**, 91 (1952); Taylor, Benedict and Strong, J. Chem. Phys. **20**, 1884 (1952); Benedict, Gailar, and Plyler, J. Chem. Phys. **21**, 1301 (1953).
[2] King, Hainer, and Cross, Phys. Rev. **71**, 433 (1947); J. H. Van Vleck, Phys. Rev. **71**, 425 (1947).

JA10. Microwave Absorption in Compressed Gases. G. Birnbaum and A. A. Maryott, *National Bureau of Standards.*—The weak absorption due to the wings of the rotational lines of HCl and HBr was measured in the pressure region 0–20 atmos by a cavity resonator method at a wavelength of 1.28 cm. Also measured were mixtures of each of these gases with He, H_2, A, N_2, CH_4, SF_6, and CO_2 at pressures up to 45 atmos. For self broadening the absorption varied nearly as p^2, and for foreign broadening the absorption varied linearly with the pressure of foreign gas, except in the case of $HX-CO_2$ mixtures. Absorption was found in the nonpolar gas CO_2 by itself ($\alpha=3.1\times10^{-5}$ cm^{-1} at 45 atmos); possible reasons for this absorption are examined. The relative pressure broadening abilities of the foreign gases were compared with those obtained from measurements at 1.28 cm on the inversion spectrum of CH_3Cl. The broadening ability increased in the order He, H_2, A, N_2, CH_4, SF_6, and CO_2 with respect to all three polar gases. Correlation of broadening ability with the polarizability and quadrupole moment of the perturber is examined.

JA11. A Microwave Spectral Series of Deuterated Hydrogen Peroxide.* J. T. Massey, C. I. Beard, and C. K. Jen, *The Johns Hopkins University.*—From the observation of more than one hundred microwave absorption lines of deuterated hydrogen peroxide,[1] a spectral series consisting of thirteen $\Delta J=0$ transitions has been established by their Zeeman and Stark effects. The frequencies of these lines converge in a smooth manner toward the high-frequency series limit at 37 526 mc/s. All lines show measurable π splitting with the magnetic field and the measured g-factor plot is representable by a function which increases with frequency. The Stark components, showing in each case a $\Delta J=0$ pattern, increase in number consecutively from line to line as the frequency is decreased. The minimum J value at the limit is most probably 4 with a possible uncertainty of ±1. The isotopic species of the series has not yet been determined with certainty. From the Zeeman calculations, it seems plausible to assume that it is an HDO_2 series. Calculation of the energy levels using the potential barrier derived from the H_2O_2 spectrum,[1] indicates that this series might come from the $n=1$ torsional vibrational state of HDO_2.

* This work was supported by the U. S. Bureau of Ordnance, Department of the Navy, under Contract NOrd 7386.
[1] J. T. Massey and D. R. Bianco, J. Chem. Phys. (to be published).

JA12. Pressure Broadening of Cyanogen Bromide in the Microwave Region.* Ralph Trambarulo, Henry Lackner, Paul Moser, and Harold Feeny, *University of Delaware.*—The self-broadening of the $J=2$ to 3, $F=5/2$ to 7/2 and 7/2 to 9/2 rotational transition of cyanogen bromide at 24.6 Kmc was investigated as a function of temperature and pressure by a method previously described.[1] This transition consists of a number of hyperfine lines which were not resolved on our spectrometer. Corrections were made for multiplet line structure and also for the mode curvature of the microwave source. The line-breadth parameter is 27.1 Mc/mm at room temperature, and the temperature variation is proportional to $T^{-1.6}$ giving an apparent collision diameter which varies with temperature. The interpretation of these results is now in progress.

* Supported by the U. S. Air Force, through the Office of Scientific Research of the Air Research and Development Command.
[1] Feeny, Moser, Lackner, and Smith, J. Chem. Phys. (to be published).

JA13. Microwave Spectrum of OCS.* Martin Peter and M. W. P. Strandberg, *M.I.T.*—The $J=1\rightarrow J=2$ transition of OCS has been studied with a microwave spectroscope designed for high sensitivity and high resolution. The line $v_3=1$ has been found at 0.85 ± 0.1 Mc/sec above the $v_1=2$ line. This is the frequency predicted with the α_3 value determined from infrared spectra by Thompson,[1] and agrees with his value within his limits of error. Several quadrupole components of OCS^{33} in the states $v_1=1$; $v_2=1$, $l=\pm1$; and $v_2=2$ have also been measured and analyzed.

* This work was supported in part by the U. S. Signal Corps, the Air Materiel Command, and the U. S. Office of Naval Research.
[1] The authors are indebted to Professor H. W. Thompson of St. John's College, Oxford, for his kindness in making his data available to them before publication.

JA14. Selection Rules in the Microwave Magnetic Resonance Spectrum of Oxygen.* M. Tinkham and M. W. P. Strandberg, *M.I.T.*—The X-band paramagnetic resonance spectrum of molecular oxygen consists of about 120 lines of observable intensity for magnetic fields below 12 kilogauss. Forty of these lines have been identified by rather tedious calculations. To aid in identifying the others, we have used a circularly polarized radiation field in the cavity containing the sample gas. This field is provided by exciting the two degenerate orthogonal TE_{111} modes in a cylindrical cavity 90° out of phase. This field configuration gives pure circularly polarized radiation only along the axis. Averaging H^2 over the cavity, 52 percent is circular in one sense, 4 percent is circular in the other sense, and 44 percent is axial. Comparison of the two observed spectra with the two senses of rotation unambiguously separates $\Delta M=\pm1$, 0 transitions. The results

are that approximately 95 lines have $\Delta M=+1$, the rest have $\Delta M=-1$. The absence of $\Delta M=0$ lines is consistent with detailed calculations which show that their intensities should be down by a factor of at least 100. Another result of the identification is that about two-thirds of the lines observed have the "forbidden" $\Delta J=\pm 2$. They are allowed here because J is not a good quantum number in the presence of the magnetic perturbation.

* This work was supported in part by the U. S. Signal Corps, the Air Materiel Command, and the U. S. Office of Naval Research.

JA15. Effects of the Deviation of O_2 from Hund (b).* M. W. P. STRANDBERG AND M. TINKHAM, *M.I.T.*—The rotational Hamiltonian of the oxygen molecule, including the spin-spin interaction, is not exactly diagonal in the Hund (b) representation $|J^2,J_Z,K^2,S^2)$ where $\mathbf{J}=\mathbf{K}+\mathbf{S}$. Hence K is not a good quantum number, and three points should be made. First, the intensities of the oxygen spin triplet spectrum at 5 mm are not exact as given by Van Vleck. He has used the matrix elements of S_Z in the Hund (b) representation rather than in the representation which diagonalizes the Hamiltonian. Thus inference of the breadths of the oxygen lines from the observed pressure and intensity, using the Van Vleck formulas, is only approximate. Exact calculation shows that such a procedure will overestimate the actual line width for low K transitions. Second, lines "forbidden" under the previous analysis now become allowed. For example, the three lowest frequency lines corresponding to changes in $K=1\rightarrow 3$ are predicted to be at 368, 522 Mc/sec, 424, 787 Mc/sec, and 487, 274 Mc/sec, with intensities respectively of 0.64×10^{-6} cm^{-1}, 38×10^{-6} cm^{-1}, and 17×10^{-6} cm^{-1}, assuming the same $\Delta\nu$ as the 5-mm lines. Third, the weak field Zeeman splittings will not exactly follow the simple vector model predictions for Hund (b).

* This work was supported in part by the U. S. Signal Corps, the Air Materiel Command, and the U. S. Office of Naval Research.

JA16. Air-Guided Propagation of Short Radio Waves Around the Earth Bulge.* THOMAS J. CARROLL, *Lincoln Laboratory.*—If the normal air be treated as a homogeneous, linear,[1] or curvilinear graded dielectric layer surmounting a perfectly reflecting curved earth, then the effect of the dielectric air layer in overcoming the earth curvature can be worked out rather completely and the field calculated in good agreement with experiment at least as far as 400 miles. Conventional airless 4/3 earth theory is adequate only out to a few tens of miles beyond the horizon, because of the neglect of the reflective effect of coherent scattering by the air dielectric. The calculation illustrates the great power in this classical problem of the complex eigenvalue method as evolved by quantum mechanicians, as well as the limitations of WKB methods pointed out by Bremmer for electromagnetic waves. The presence of the normal air layer, hitherto neglected except for its refractive effect, can thus be proved to have considerable practical importance to radio technology.

* Supported jointly by the U. S. Army, Navy, and Air Force under contract with the Massachusetts Institute of Technology.
[1] T. J. Carroll and R. M. Ring, Lincoln Laboratory Technical Report 38.

FRIDAY MORNING AT 9:30

Shoreham, West Ballroom

(J. B. PLATT presiding)

Meson Scattering; Meson Absorption; Mesonic Atoms

K1. The Parity of the Pion.* WILLIAM CHINOWSKY AND JACK STEINBERGER, *Columbia University.*—The best evidence presently available for the negative relative parity of pion and nucleon comes from the experiments of Panofsky *et al.*[1] which show, indirectly, that the process $\pi^-+D\rightarrow 2N$ is allowed, even when the initial system is in an S state. The reaction itself has, however, not been observed before. In this experiment, π^- mesons came to rest in a cylinder of liquid deuterium, 3 in. in diameter$\times 3\frac{3}{4}$ in. high. The two 70 Mev neutrons are detected in liquid scintillation counters $2\frac{1}{2}$ in. in diameter and 2 in. along the direction of motion of the neutron. The efficiency of each counter for the detection of such neutrons is ~5 percent. We discriminate against charged particles and high-energy γ rays by means of anticoincidence counters, and against low energy γ rays and neutrons by means of pulse height requirements. N-N coincidences are measured as a function of the angle subtended by the two detectors at the target. The observed coincidence rate is peaked at 180° with an angular width which is just the resolution of the apparatus. The absolute intensity can be estimated, and roughly agrees with that predicted by Panofsky. The experiment therefore confirms the evidence that the pion is not scalar.

* This work was performed under the joint program of the U. S. Office o Naval Research and the U. S. Atomic Energy Commission.
[1] Panofsky, Aamodt, and Hadley, Phys. Rev. 81, 565 (1951).

K2. Charge Exchange Scattering of Stopped π^- Mesons in Deuterium.* JACK STEINBERGER AND WILLIAM CHINOWSKY, *Columbia University.*—Using an arrangement similar to that of the preceding abstract, we have searched for neutral mesons produced by π^- mesons stopped in D_2, according to the reaction

$$\pi^-+D\rightarrow\pi^0+N+N_0. \qquad (1)$$

The neutral mesons were to be detected by observing the two π^0 decay γ rays in coincidence in two telescopes, each consisting of two $4\frac{1}{2}$ in. diameter scintillation counters with $\frac{3}{4}$ in. polyethylene absorber between them. A $\frac{1}{4}$ in. Pb converter is in front of each telescope. This system is insensitive to the neutrons from the competing process $\pi^-+D\rightarrow 2N$. We find a small number of $\gamma-\gamma$ coincidences, corresponding to a fractional rate for process (1) of 0.0008 ± 0.0003. We believe, however, that such a rate can be accounted for by an expected small hydrogen impurity in the deuterium.

* This work was performed under the joint program of the U. S. Office of Naval Research and the U. S. Atomic Energy Commission.

K3. (Abstract withdrawn.)

K4. Total Cross Sections for Scattering of Positive Pions by Hydrogen.* J. BLASER, J. ASHKIN, F. FEINER, J. GORMAN, AND M. O. STERN, *Carnegie Institute of Technology.*—External π^+ beams of energies ranging from 135 to 197 Mev have been used for the measurement of total cross sections by an attenuation experiment. Liquid hydrogen as well as CH_2 and C were used as scatterers. Possible errors introduced by contamination of the π^+ beam by protons have been eliminated by use of time of flight and pulse-height selection. The corrected cross sections have typical uncertainties of ± 5 percent and rise from 120 mb at 135 Mev to 200 mb for energies between 170 to 196 Mev. They follow very well the curve representing three times the total cross section for π^- scattered on hydrogen.[1] This supports the idea of the dominant role played by the state of angular momentum 3/2 and isobaric spin 3/2.

* Research partially supported by the U. S. Atomic Energy Commission.
[1] Ashkin *et al.*, Phys. Rev. (to be published).

K5. π^- P Collisions at 1.5 Bev. I.* W. D. WALKER, J. CRUSSARD, AND M. KOSHIBA, *University of Rochester.*—About 70 $\pi^- P$ collisions have been found from scanning G-5 emulsions exposed to the Brookhaven Cosmotron. The criteria for acceptance and rejection of these interactions will be discussed. The results at the present time are as shown in Table I. The

TABLE I.

Products	No. cases
π^-+P	16
$\pi^-+P+\pi^0$	31
$\pi^++\pi^-+N$	11
π^0+N, $2\pi^0+N$, $\Lambda^0+\theta^0$	13
$\pi^++2\pi^-+P$	1

angular distributions from these interactions will be discussed. In general the proton (or neutron) almost always go backward in the center of mass system. The π^- goes forward and the secondary meson usually goes out at an angle of the order of 120° with respect to the π^-.

* This work was assisted by the U. S. Atomic Energy Commission.

K6. π^- Interactions at 1.5 Bev. II.* J. CRUSSARD, W. D. WALKER, AND M. KOSHIBA, *University of Rochester.*—In the course of scanning for the $\pi^- - P$ collisions of the previous abstract many other interactions were found. A mean free path of 25 cm was obtained with about 25 percent of the interactions being diffraction scatterings of 1°–2°. Several interactions seemed to be interpretable as $\pi^- - N$ interactions. These interactions consisted usually of a large angle deflection of the π^- with only a β emerging from the vertex of the interaction. The results are given in Table I. Interactions with light nuclei have been subdivided as to whether 0, 1, 2, 3π mesons emerge from the interaction. The results of these studies show qualitative agreement with the results of the $\pi^- - P$, and $\pi^- - N$ interactions as to the relative number of

TABLE I.

Products	No. cases
π^-+N, $\pi^-+N+\pi^0$	36
$2\pi^-+P$	7
$\pi^++2\pi^-+N$	1

the different interactions except in one respect. There is an indication of another process which may be a many body collision in the nucleus.

* Assisted by the U. S. Atomic Energy Commission.

K7. Scattering of 145-Mev π^+ by Hydrogen in Emulsion. JAY OREAR, *University of Chicago,* AND C. H. TSAO, J. J. LORD, AND A. B. WEAVER, *University of Washington.*—Standard Ilford G5 plates have been exposed to a flux of 7.7×10^5 particles per cm² in the 145-Mev (nominal energy) external π^+ beam of the Chicago cyclotron. About two pion-proton scatterings can be found and measured per hour using area scanning techniques.[1] The possibility of obtaining a large number of events will make feasible a determination of the phase shifts more accurate than previously obtained. As of February 15, 54 events had been analysed to give a total cross section of (169 ± 23) millibarns. The mean pion energy will be determined from events where the proton stops in the emulsion. So far too small a number of such events have been found to make an accurate determination. Least squares analysis of the angular distribution in the barycentric system gives $d\sigma/d\omega = (5.0\pm2.5) - (6.8\pm3.6)\cos\chi + (25.2\pm10.0)\cos^2\chi$ in millibarns per steradian. This curve gave a good fit to the data lumped into six experimental points each containing nine events. With improved statistics this experiment offers the possibility of detecting d-wave phase shifts. We hope to improve the statistics by at least a tenfold increase of the data.

[1] Jay Orear, Phys. Rev. **92**, 156 (1953).

K8. High-Energy Electrons in the Capture of μ^- Mesons by Complex Nuclei.* S. LOKANATHAN, J. STEINBERGER, AND H. B. WOLFE, *Columbia University.*—We have searched for high-energy electrons produced in the reactions $\mu^-+p\rightarrow p+e^-$ and $\mu^-+n\rightarrow n+e^-$. These electrons are expected to have an energy distribution peaked near 100 Mev, and to have an average energy of 85 Mev. μ^- mesons produced in the Columbia University cyclotron were stopped in targets of several materials. The electrons were to be observed in a three-counter telescope in delayed coincidence with the incoming meson. The system was calibrated by means of the electrons from normal μ^- decay, and then absorber was inserted to discriminate against these. No positive evidence for the reaction was found. The fraction of *captured* muons which result in electrons is (0.007 ± 0.031) for Al, (-0.0007 ± 0.0047) for Cu, and (-0.0014 ± 0.0043) for Cd. We can therefore place an upper limit of 0.003 on this fraction. This implies that the strength of the coupling, g^2, for this type of β-decay process is at least 2000 times smaller than that of the dominant capture reaction.

* This work was performed under the joint program of the U. S. Office of Naval Research and the U. S. Atomic Energy Commission.

K9. Production of Neutrons by Negative μ Mesons Stopped in Various Absorbers.* D. R. JONES, *Washington University.*†—Measurements of the production of neutrons by negative mesons which stop and interact in two materials, sodium and magnesium, are reported. The mean number of neutrons emitted per interaction was measured and found to be 0.6 ±0.2 for magnesium and 1.0 ± 0.4 for sodium, where the uncertainties quoted include an estimated contribution from systematic sources as well as those of a statistical nature.

The data confirm that relative neutron production in magnesium is less than in lead, but show that it is not zero. Neutron production in sodium is also shown to be nonzero and probably greater than in magnesium, though less than in lead. In the course of the experiment a value of $1.18^{+0.18}_{0.14}$ μsec (statistical) was found for the mean life of negative μ mesons in sodium.

* Supported by the joint program of the U. S. Office of Naval Research and the U. S. Atomic Energy Commission.
† Now at the University of Cincinnati.

K10. X-Rays from π Mesic Atoms.* A. D. McGuire, M. Camac, M. L. Halbert, and J. B. Platt, *University of Rochester.*—The π^- meson beam of the University of Rochester 240 Mev synchrocyclotron was used to study the x-rays produced by pion transitions between atomic bound states. Particular attention was paid to the $2p-1s$ transitions. Well collimated, magnetically analyzed 50 Mev π^- mesons were detected by a 3 fold counter telescope and allowed to stop in various materials of low Z. The resulting x-rays were detected by a NaI scintillation counter in time coincidence with the telescope. The energy loss in the NaI crystal was recorded using a 25 channel pulse-height selector. The transitions were identified on the basis of pulse height in the NaI counter which was calibrated with known energy x-rays from radioactive sources. The probability that a stopped π^- meson makes a $2p-1s$ radiative transition was measured for mesons stopping in Be, B, C, N, and O. Preliminary results are 0.21, 0.14, 0.065, 0.04 and 0.01, respectively, with an error of 0.02 in each case. Account was taken of (1) and NaI counter efficiency and solid angle, (2) attenuation and scattering of the x-rays in leaving the stopping material, and (3) muon and electron contamination of the pion beam.

* Work supported by the U. S. Atomic Energy Commission.

K11. Energy Measurements of Meson X-Rays.* M. B. Stearns, M. Stearns, L. Leipuner, and S. DeBenedetti, *Carnegie Institute of Technology.*—The critical absorption technique is being used to study the x-ray energy of the $2p-1s$ transition of pions captured in beryllium. Since a small energy shift could be contributed by secondary effects (Compton degradation, fluorescent x-rays) other lines of similar energy were examined. The π-Phosphorus M-line computed for a point nucleus (without polarization and radiative corrections) is below the stated value[1] of the K edge of cerium ($Z=58$) for $m_\pi/m_e=272.5$, and above it for $m_\pi/m_e=273$. Comparative absorption measurements in successive elements show that it is above this edge. This indicates that the Compton degradation does not appreciably affect the result and gives a lower limit for the meson mass. Similar measurements show that the π-Fluorine L-line and μ-Beryllium K-line fall between the predicted edges. The π^--Beryllium K-line should fall 330 volts above the edge of Neodymium ($Z=60$) for $m_\pi/m_e=273$. Instead, the experiments indicate that it lies below this edge, an effect possibly connected to a repulsion between the nucleus and the pion in the 1s state. Measurements of energies of other lines are in progress.

* Supported by the U. S. Atomic Energy Commission.
[1] Hill, Church, and Mihelich, Rev. Sci. Instr. **27**, 523 (1952).

K12. Mass of the μ^- Meson from Mesonic X-Rays.* S. Koslov, V. Fitch, and J. Rainwater, *Columbia University.*—The precise measurement of mesonic atom x-ray energies in the 15–90 kilovolt range has been applied to the determination of negative meson masses. A filter technique using thin filters of various elements between the NaI (Tl) crystal of a scintillation spectrometer[1] and the mesonic atom allows a statement to be made as to whether the x-ray energy for a transition with small natural line width lies above or below the photoelectric K-shell absorption limit in a particular filter element. The precision of an upper or lower limit for the x-ray energy is thus equivalent to high-precision absorption limit measurements.[2] $2p-1s$, $3d-2p$, and $4f-3d$ mesonic transitions in various elements have been selected for their proximity to K-absorption limits. Energy level shifts due to nuclear penetration are small in the particular transitions used. Preliminary results indicate that the mass of the μ^- meson is between 206.36 and 208.22 electron masses (subject to quantum electrodynamic corrections). Measurements now in progress indicate that closer assignments of the μ^- mass limits are possible and will be reported. This method is also being applied to the mass of the π^- meson.

* This work was performed under the joint program of the U. S. Office of Naval Research and the U. S. Atomic Energy Commission.
[1] V. Fitch and J. Rainwater, Phys. Rev. **92**, 789 (1953).
[2] Y. Cauchois and H. Hulubei, *Table de Constantes Selectionnes Longuers D'Onde Des Emissions X Et Des Discontinuities D'Absorption X* (1947).

Friday Morning at 9:30

Sheraton Park, Continental Room

(M. L. Perlman presiding)

Radioactive Nuclei, II

KA1. Disintegration of Ce^{139}. C. H. Pruett and R. G. Wilkinson, *Indiana University.**—The radiations of 140-day Ce^{139} have been examined with a 180° magnetic spectrometer and a coincidence gamma-scintillation spectrometer. Sources were prepared from deuteron activated lanthanum. The electron spectrum consists only of Auger electrons and conversion electrons corresponding to the K, L, and M conversion of a single gamma ray at 166 kev. No positrons were found. The $K/L+M$ ratio was found to be 6.6 and the ratio of Auger electrons to K conversion electrons was 0.34. The simple nature of the decay was confirmed by the scintillation pulse height spectrum. Only photoelectron peaks resulting from LaKα x-rays and the 166-kev gamma ray were present. The results of a scintillation coincidence experiment, when combined with the beta-ray spectrometer data yield a value the K-conversion coefficient consistent with an M-1 classification of the gamma ray. This was further substantiated by delayed coincidence measurements, the results of which place a lower limit of 10^{-8} sec on the lifetime of the single excited state.

* Supported by the joint program of the U. S. Office of Naval Research and U. S. Atomic Energy Commission.

KA2. Anisotropic Gamma Radiation from Aligned Ce^{141} Nuclei.* E. Ambler, R. P. Hudson, *National Bureau of Standards*, and G. M. Temmer, *Department of Terrestrial Magnetism.*—We have observed a fourteen percent anisotropy in the counting rate of the 143-kev gamma ray following beta decay of Ce^{141}. The alignment was achieved by the method of

Bleaney (zero residual field), using three single crystals of cerium-magnesium nitrate, reaching demagnetization temperatures of about 0.003°K.[1] The alignment occurs in a *plane* rather than along an axis, as predicted.[2] Scintillation counter A was located in that plane and counter B at right angles to it. Some twelve demagnetizations gave essentially identical results for the 400-second warm-up period, showing the decay of the anisotropy. No effect was observed when the counters viewed the sample at 45° and 135° to the alignment plane. The fact that counting rate A was higher permits us to conclude that the gamma-ray transition in Pr^{141} is predominantly magnetic dipole. Internal conversion data[3] admit both $M1$ and $E2$ transitions ($7/2^+ \rightarrow 5/2^+$). The gamma ray in Pr^{141} is also very weakly Coulomb-excited ($E2$ process)[4] supporting our observations. Estimates of the magnetic moment of Ce^{141} will be made.

* Assisted by the U. S. Office of Naval Research.
[1] J. M. Daniels and F. N. H. Robinson, Phil. Mag. **44**, 630 (1953).
[2] R. J. Elliott and K. W. H. Stevens, Proc. Roy. Soc. (London) **A215**, 437 (1952).
[3] E. Kondaiah, Phys. Rev. **83**, 471 (1951).
[4] G. M. Temmer and N. P. Heydenburg, Phys. Rev. **93**, 351 (1954).

KA3. The Disintegration of Pm^{150}.*† VERA KISTIAKOWSKY FISCHER, *University of California and U. S. Naval Radiological Defense Laboratory.*—The gamma rays of the 2.7 hour half-life isotope Pm^{150} have been investigated with a "grey wedge" scintillation spectrometer in coincidence either with a proportional counter or with a scintillation counter and single channel pulse-height analyzer. Beta-ray spectrometer studies previously reported[1] show 2.01- and 3.00-Mev negatrons to be emitted. More than ten gamma rays ranging in energy from 0.14 to 2.4 Mev are observed in coincidence with the two beta particles. Their energies will be given and a possible decay scheme will be discussed. Some conclusions on the beta decay stability of Nd^{150} will be drawn.

* This work was sponsored in part by the U. S. Atomic Energy Commission.
† The completion of this study was made possible by the Sarah Berliner fellowship (1953–54) of the American Association of University Women.
[1] Vera Kistiakowsky, Phys. Rev. **87**, 859–60 (1952).

KA4. Lifetime Measurements of Fast E2 Transitions in Even-Even Nuclei. A. W. SUNYAR, *Brookhaven National Laboratory.**—A delayed coincidence scintillation spectrometer of short resolving time has been utilized in half-life determinations of a number of fast[1] $E2$ transitions in even-even nuclei. Our results are summarized in Table I. With the exception of the Po^{210} transition, all transitions are between the $2+$ first excited state and the $0+$ ground state of even-even nuclei. A consideration of the matrix elements for all $E2$ transitions of measured lifetime in even-even nuclei shows a smooth variation of the matrix element with Z. Maximum matrix elements occur near $Z=68$. The matrix elements reduce as the proton number increases toward the magic number 82. At $Z=84$, the matrix element for the Po^{210} transition is large.

TABLE I.

Nucleus	E (kev)	$T_{1/2} \times 10^9$ seconds
Sm^{152}	122	1.40
Hf^{180}	93	1.39
W^{182}	100	1.27
Os^{188}	155	0.65
Po^{210}	46.4[2]	1.52

* Work done under the auspices of the U. S. Atomic Energy Commission.
[1] M. Goldhaber and A. W. Sunyar, Phys. Rev. **83**, 906 (1951).
[2] Mihelich, Schardt, and Segrè (private communication).

KA5. Low-Energy Transitions in Gadolinium and Related Rare-Earth Activities.* E. L. CHURCH,† *Argonne National Laboratory,* AND M. GOLDHABER, *Brookhaven National Laboratory.*—The neutron-capture conversion-electron spectrum of gadolinium has been investigated with a 180°-focusing beta-ray spectrograph. Transitions of 79.1, 181.7 and 88.8, 198.7 kev were observed using normal gadolinium. Comparison with a target having its isotopic constitution altered by long-term neutron bombardment indicates the assignment of the above pairs of transitions to $_{64}Gd^{158}$ and $_{64}Gd^{156}$, respectively. Comparison of fission-product and normal europium activities assigns transitions[a] of 121.8, 244.3 and 123.4, 247.7 kev to $_{62}Sm^{152}$ and $_{64}Gd^{154}$, respectively. The electric-quadrupole character of these transitions will be discussed with reference to the collective model. Levels in Gd^{156} were also populated by beta decay from 14.0±1.0-day Eu^{156} formed by neutron capture in long-lived Eu^{155}. The decay of Eu^{155} excites strong transitions of 59.8, 86.3, and 105.1 kev in $_{64}Gd^{155}$. Reported gammas of ~130 kev are due to a misinterpretation of the conversion lines of a Eu^{156} impurity. The decay of Gd^{153} yields transitions of 69.4, 97.3, and 103.1 kev in $_{63}Eu^{153}$. Only the first and last of these are seen following the decay of Sm^{153}. Possible decay schemes of these nuclei will be considered. (Absolute energy uncertainties ~0.5 kev.)

* Based in part on a doctoral investigation carried out at Brookhaven, 1951–1952.
† On loan from Frankford Arsenal, Philadelphia, Pennsylvania.

KA6. Radiations from Ho^{164}.* H. N. BROWN,† F. B. SMITH, AND R. A. BECKER, *University of Illinois.*—Samples of holmium oxide and metallic holmium, irradiated with 22-Mev x-rays, yielded a 36.7±0.5-minute activity which was attributed to Ho^{164}. This is consistent with the values given in the table of K. Way.[1] Pulse-height measurements, with NaI (Tl) and a proportional counter, indicated the presence of radiation of energies 37, 46, 73, and 90 kev. Magnetic spectrometer data yielded conversion electrons consistent with $90-L$, $90-M$, $73-K$, $73-L$, $73-M$, $37-L$, $(37-M)+90-K$), $46-L$, and $46-M$ superimposed upon a beta continuum with end-point 990±30 kev. The continuum is consistent with two groups separated by about 90 kev. Pulse-height measurements of coincidences showed gamma-gamma coincidences: 46–73, 46–46, and 37–46, and beta-gamma coincidences involving 90- and 49-kev radiation The 49-kev radiation was attributed to characteristic erbium x-rays. Most of the 46-kev radiation is thought to be characteristic x-rays from dysprosium, consistent with K-capture branching of the parent nucleus. All radiations followed, within experimental error, the 36-minute half-life. Tentative level schemes will be discussed.

* Supported in part by the U. S. Atomic Energy Commission and U. S. Office of Naval Research. The Ames Laboratory is to be thanked for rare earth samples.
† National Science Foundation fellow.
[1] Nuclear Data, Natl. Bur. Standards Circ. 499.

KA7. The Disintegration of Ta^{182}. J. W. MIHELICH, *Brookhaven National Laboratory.**—The excited levels of W^{182} reached by β emission from Ta^{182} and electron-capture from Re^{182} have been investigated using scintillation counters, β spectrometers, and coincidence techniques. Multipolarity assignments have been made for all transitions. The data indicate that of the eight possible partial level arrangements suggested by Muller *et al.*,[1] using their accurate energy determinations, only (b) of Fig. 14[1] is reasonable. It has been established that the 100-kev transition from the first excited $2+$ level is in coincidence with the γ rays of 1121 and 1188 kev, but not with the one of 1223 kev. It is probable that the level designated as "f"[1] has an excitation energy of 1223 kev and that the transitions of 1121 and 1223 kev proceed from it, while the transition of 1188 kev proceeds from level "a" at 1291 kev, and that this level is responsible for the lifetime of 1.03×10^{-9} sec recently observed.[2]

* Work done under the auspices of the U. S. Atomic Energy Commission.
[1] Muller, Hoyt, Klein, and DuMond, Phys. Rev. **88**, 775 (1952).
[2] A. W. Sunyar, Phys. Rev. (to be published).

KA8. Gamma-Ray Studies of Re^{186}.* J. P. HURLEY AND P. S. JASTRAM, *Washington University.*—A study has been made of the decay scheme of Re^{186}, using a scintillation coincidence spectrometer, in an attempt to resolve the apparently contradicting results of the magnetic spectrometer and the beta-gamma angular correlation measurements: the pronounced (70 percent) beta-gamma anisotropy which should result from a first-forbidden unique transition is not found. A test of the possibility that the correlation is attenuated by interaction between the nuclear magnetic dipole or electric quadrupole moment with the magnetic field of the electron shell is afforded by the angular correlation between the gamma rays which cascade through the state in question. This work is now in progress with preliminary results indicating that both transitions are electric quadrupole and requiring that the spin assignments be 0–2–2 for the ground state and the two excited states of Os^{186}.

* Supported by the joint program of the U. S. Office of Naval Research and the U. S. Atomic Energy Commission.

KA9. The Beta Spectra of Re-186 and Re-188.* DONALD GUSS, LAWRENCE KILLION, AND F. T. PORTER, *Washington University.*—The 14-cm radius of curvature 180° spectrometer has been used to reinvestigate in detail the shapes of the beta spectra of Re-186 and Re-188. For Re-186 the assumption that the ground-state transition (1064±4-kev end point) has the allowed shape yields a spectrum for the first inner group which does not have an allowed shape. Application of the ($\Delta I=2$, yes) unique correction factor gives a linear *FK* plot for the first inner group with end-point energy 928±12 kev in good agreement with the observed 137-kev gamma ray from the 1st excited state in the even-even daughter Os-186. For the ground-state transition log ft = 7.71; for the transition to the first excited state log $(2I_f+1)f_1t=8.35$. These results suggest assignment of zero spin and odd parity for ground state of Re-186 rather than spin 1.[1] For Re-188 no analysis has been found that will yield an unambiguous interpretation of the measured spectra. It appears possible that both of the principal beta groups have nonallowed shapes.

* Supported by the joint program of the U. S. Office of Naval Research and U. S. Atomic Energy Commission.
[1] F. R. Metzger and R. D. Hill, Phys. Rev. **82**, 646 (1951).

KA10. The Radiations of Ir^{192m}.* J. P. MIZE, J. W. STARNER, AND M. E. BUNKER, *Los Alamos Scientific Laboratory.*—An investigation of the radiations accompanying the radioactive decay of Ir^{192m} (1.42-min) has been performed with a NaI(Tl) scintillation spectrometer and an aluminum-lined proportional counter. An interest in this isomer was prompted by the previously reported gamma-ray continuum accompanying the decay of Ir^{192m} and the proposed interpretation of the continuum as being engendered by "two-quantum" emission.[1,2] Examination of the photon spectrum revealed the presence 57.4-kev quanta, iridium *L* x-rays, and a low-intensity continuum extending to ~50 kev. From a measurement of the relative intensities of the 57.4-kev quanta and the iridium *L* x-rays produced by interval conversion of the 57.4-kev transition, we have calculated the *L*-shell conversion coefficient of this gamma ray. If one assumes that the gamma-transition is *E*3, then $\alpha_L \simeq 750$. On the basis of absorption and coincidence measurements, the continuum is attributed to bremsstrahlung produced by conversion electrons from the highly converted 57.4-kev gamma ray.

* Work done under the auspices of the U. S. Atomic Energy Commission.
[1] Goldhaber, Muehlhause, and Turkel, Phys. Rev. **71**, 372 (1947).
[2] E. der Mateosian and M. Goldhaber, Phys. Rev. **82**, 115 (1951).

KA11. The Decay of Pt^{199}. J. M. LEBLANC, J. M. CORK,* AND S. B. BURSON, *Argonne National Laboratory.*—The beta and gamma rays associated with the decay of 30-min Pt^{199} have been studied using 180° photographic spectrometers and a 10-channel coincidence scintillation spectrometer. The beta rays were studied by measuring their attenuation in Al. Sources were obtained by irradiating normal PtO in the Argonne heavy water reactor. Nine gamma rays of energies 0.07, 0.197, 0.246, 0.316, ~0.48, 0.54, 0.71, 0.78, and 0.96 were found to decay with a 30-min half-life and are therefore assigned to this activity. Conversion electron lines were obtained for the 0.197, 0.246, and 0.316-Mev gamma rays. The results of beta-gamma coincidence measurements indicate that the 0.197, 0.246, 0.316, and 0.54-Mev gamma-rays are in coincidence with beta rays having an end point energy of about 1.2. Gamma-gamma coincidences will be discussed.

* University of Michigan.

KA12. The Decay of Hg^{196}.* C. H. BRADEN, E. T. PATRONIS, JR., AND L. D. WYLY, *Georgia Institute of Technology.*—We have investigated the Hg activities produced by the bombardment of Au with protons in the Oak Ridge 86-in. cyclotron. Hg was chemically separated from Au and Pt. Scintillation counters were used to determine the gamma spectrum of the decay. Protons slowed to 12 Mev produced an activity showing a weak 280-kev gamma line in addition to a 130-kev line and a strong line of about 70 kev. The 130-kev line is definitely associated with the *K*-capture decay of Hg^{197}. The fact that other known lines in the decay of Hg^{197} were not resolved is attributed to the strong internal conversion. Bombardment with 20-Mev protons produced an activity that shows gamma lines of 1200 kev (very weak), 810 (weak), 580 (weak), and 270 (strong). The latter three lines all decay with the same half life of approximately 42±5 hours and are all in coincidence with the strong x-ray line of about 70 kev. The 1200-kev line seems to also decay with the same half-life, but owing to the low intensity our measurements are not precise. We assign these lines to the decay of Hg^{195} produced by the Au $(p,3n)$ Hg^{195} reaction. The decay of Hg^{195} therefore gives rise to Au^{195} which is known to decay with a half-life of 183 days. A separation of Au from the Hg after a few weeks shows a Au activity of long half-life.

* Supported in part by a grant from the National Science Foundation.

KA13. Resonance Fluorescence with Nuclei: Tl^{203}.* F. R. METZGER AND W. B. TODD, *Bartol Research Foundation.*—Hg^{203} decays to the ground state of Tl^{203} by the emission of a beta ray followed by a 280-kev gamma ray. The 280-kev gamma rays were used to irradiate thallium in an attempt to observe resonance fluorescence. In order to utilize the recoil momentum distribution produced by the beta-ray emission, gaseous sources of Hg^{203} were used. However, the lifetime of the 280-kev state turned out to be longer than the collision time of the Tl^{203*} ions in the mercury vapor. Thus most of the recoiling Tl^{203*} nuclei had reached thermal equilibrium before they emitted the 280-kev radiation. The increase in counting rate observed upon heating of the Hg^{203} sources to 900 degrees centigrade was therefore almost completely due to the thermal Doppler broadening of the 280-kev line. Based on preliminary measurements with two different sources the lifetime τ_γ for the 280-kev transition is estimated as $(1\pm0.4)\times10^{-9}$ sec. From Weisskopf's formula[1] one estimates for a 280-kev magnetic dipole transition a lifetime of 1.5×10^{-12} sec.

* Assisted by the joint program of the U. S. Office of Naval Research and the U. S. Atomic Energy Commission.
[1] V. F. Weisskopf, Phys. Rev. **83**, 1073 (1951).

KA14. Gamma-Ray Spectrum of Po^{209}. E. H. DAGGETT AND G. R. GROVE, *Mound Laboratory.**—A polonium sample was produced at ORNL by the bombardment of bismuth targets with 20-Mev protons. The sample contained a mixture of the polonium isotopes of mass 208 and 209 with a negligible amount of Po^{192}. Measurements were made of the isotopic ratio from the molecular spectrum and the alpha activity by calorimetry. The spectrum obtained with a NaI

(Tl) crystal and pulse-height analyser showed the existence of gamma rays with energies of about 270, 570, and 865 kev. The 803-kev gamma ray of Po^{210} was not detectable. This spectrum is attributed to Po^{209} since there is no gamma radiation from Po^{208}.[1] The intensity of the 865-kev gamma ray relative to the gamma ray of a calibrated Po^{210} sample was estimated to be about 7.5×10^{-3} quanta per 209 alpha particle. Coincidence measurements between various pairs of gamma rays indicated that only the 270- and 570-kev quanta were in cascade and existed with about the same relative intensity as the 865-kev gamma ray.

* Mound Laboratory is operated by Monsanto Chemical Company for the United States Atomic Energy Commission.
[1] Templeton, Howland, and Perlman, Phys. Rev. **72**, 758 (1947).

KA15. The $\alpha-\gamma$ Angular Correlation in the Decay of Ra^{224}, Ra^{226}, and Pu^{238}. J. C. D. MILTON AND J. S. FRASER, *Chalk River Laboratories.*—The angular correlation of the 241-, 186-, and 45-kev γ rays from the first excited states of the daughter nuclei following the α decay of Ra^{224}, Ra^{226}, and Pu^{238} have been measured using NaI detectors with pulse-height selection for both radiations and a coincidence resolving time of 1.4×10^{-8} sec. The data were taken automatically at 5° or 15° intervals between 90° and 220°. A weighted least squares fit to $W(\theta)=1+A_2P_2(\cos\theta)+A_4P_4(\cos\theta)$ gave for Ra^{224}, Ra^{226}, and Pu^{238}, respectively: $A_2=0.534\pm0.014$, 0.490 ± 011, 0.330 ± 037; $A_4=-1.739\pm0.023$, -1.299 ± 0.023, -1.145 ± 0.065. The errors shown are statistical only. Angular resolution corrections have been applied. The transitions are of the type 0–2–0 for which the theoretical values are $A_2=0.714$, $A_4=-1.714$. That the quadrupole moment is responsible for the deviations from theory is indicated by the facts that A_4 is attenuated less than A_2,[1] and that the attenuation increases with increasing neutron number.[2] The effect of the chemical constitution of the sources was not investigated. They were evaporated from solution on mica 1 mgm/cm² thick: the Ra^{224} from radiothorium in HNO_3, Ra^{226} from radium in HCl and Pu^{238} from plutonium in HNO_3.

[1] A. Abragam and R. V. Pound, Phys. Rev. **92**, 943 (1953).
[2] K. W. Ford, Phys. Rev. **90**, 29 (1953).

KA16. Gamma Radiation from the Decay of UX_2 (Pa^{234}). W. G. CROSS AND T. A. EASTWOOD, *Chalk River Laboratories.*—The gamma rays from the decay of UX_2 have been measured with a NaI scintillation spectrometer. Lines were observed at 0.758 ± 0.010, 0.998 ± 0.010, 1.49 ± 0.03, 1.7 ± 0.06 and 1.84 ± 0.03 Mev, with respective relative intensities of 0.65, 1.00, 0.03, 0.03, and 0.1. Between 0.3 and 0.7 Mev no nuclear gamma ray was observed with relative intensity greater than 0.1, the limit of detection being set by the relatively strong bremsstrahlung spectrum. No $\gamma-\gamma$ coincidences were detected between the 0.998- and 0.758-Mev lines. The 0.998-Mev radiation occurs in 1 percent of the disintegrations. An upper limit of 2×10^{-3} per disintegration was obtained for the emission of γ rays between 0.78 and 0.83 Mev, for which conversion electrons have been reported.[1,2] The observed γ intensities are considerably smaller than would be required to fit the β spectrum analysis made by Heerschap *et al.*[2]

[1] Bradt, Heine, and Scherrer, Helv. Phys. Acta **16**, 455 (1943).
[2] Heerschap, Hok, and Sizoo, Physica **16**, 767 (1950).

FRIDAY MORNING AT 9:30

Shoreham, Main Ballroom

(P. H. ABELSON presiding)

Electric Excitation of Nuclei; Photonuclear Reactions

Invited Paper

L1. Coulomb Excitation of Nuclear Energy Levels by Alpha-Particles. G. M. TEMMER, *DTM, Carnegie Institution of Washington.* (30 min.)

Contributed Papers

L2. Electric Excitation of Mn^{55} with Protons. HANS MARK, CLYDE MCCLELLAND, AND CLARK GOODMAN,* *M.I.T.*—Thin (20- and 40-kev) targets of Mn evaporated on Pb were bombarded with monoenergetic protons from the Rockefeller Generator. The yield of the 133-kev γ ray[1] was measured as a function of proton energy E_p between 0.550 and 2.40 Mev. From 0.55 to 1.0 Mev the normalized yield fits the characteristic electric quadrupole excitation function fairly well. Above 1.0 Mev, the yield shows marked resonances indicating compound nucleus formation. Five γ rays, having energies of 133, 420, 505, 650, and 975 kev, were observed at $E_p=2.12$ Mev. The 133 kev γ ray comes from the first excited state of Mn^{55}. The 420- and 975-kev γ rays probably come from[2] $Mn^{55}(p,n,\gamma)Fe^{55}$. The origin of the 505- and 650-kev γ rays is not yet certain. Measurement of the absolute cross section of the excitation of the 133-kev γ ray at low proton energies is in progress.

* This work has been supported by the joint program of the U. S. Office of Naval Research and the U. S. Atomic Energy Commission.
[1] Reported as 128 kev by G. M. Temmer and N. P. Heydenburg, Bull. Am. Phys. Soc. **29**, 10 (1954).
[2] P. H. Stelson and W. M. Preston, Phys. Rev. **82**, 655 (1951).

L3. Electric Excitation of Gold.* J. EISINGER, C. F. COOK, AND C. M. CLASS, *Rice Institute.*—The gamma-ray spectrum obtained from the electric excitation of gold has been studied using protons accelerated by the 5.5-Mev Van de Graaff. At a bombarding energy of 3-Mev, lines at 191, 279 and 555 kev were observed. The thin target yield curves of the 279- and 555-kev lines have been measured between 2 and 5 Mev and were found to lie substantially above the theoretical curves[1] at the high energies as was found by Goldburg and Williamson.[2] The angular distributions of these lines were also obtained. The data for the 279-kev radiation can be fitted by $1-0.19\cos^2\theta$ and the distribution of the 555-kev radiation is $1+0.21\cos^2\theta$. The latter distribution agrees with theory[1] if it is assumed the excited state has a spin of 7/2.

* Work supported by the U. S. Atomic Energy Commission.
[1] K. Alder and A. Winther, Phys. Rev. **91**, 1578 (1953).
[2] W. I. Goldburg and R. M. Williamson, Bull. Am. Phys. Soc. **29**, No. 1, 10 (1954).

L4. Coulomb Excitation of Gold. W. I. GOLDBURG, S. A. COX, AND R. M. WILLIAMSON, *Duke University.*—A further study has been made of the strongest gamma rays (277±5 kev

and 545±8 kev) resulting from the Coulomb excitation of gold by four Mev protons.[1] The anisotropy of the 277-kev gamma ray is −15±5 percent; this agrees best with a 7/2→5/2 *M*1 transition. The 545-kev gamma-ray anisotropy is +25±5 percent in agreement with a 7/2→3/2 *E*2 transition. Coincidence counting equipment of 0.1 μsec resolving time has been used to determine that the number of coincidences between the 277 kev and a possible 268-kev cascade gamma is less than 5 percent of the number of 277-kev transitions.[2] Hence, we are led to the conclusion that the lower-energy gamma ray goes to the ground state and is the same one observed from beta-decay experiments[3] to occur at 279 kev—in spite of the observed angular distribution. The coincidence of the 137-kev and the 166-kev gamma rays in Ta was verified. A more careful survey of weaker lines from a spectroscopically pure gold sample is now in progress.

* This work supported by the U. S. Atomic Energy Commission.
[1] W. I. Goldburg and R. M. Williamson, Bull. Am. Phys. Soc. **29**, No. 1, 10 (1954).
[2] K. Alder and A. Winther, Phys. Rev. **91**, 1578 (1953).
[3] J. W. Mihelich and A. de-Shalit, Phys. Rev. **91**, 78 (1953).

L5. Coulomb Excitation *vs* Compound Nucleus Formation in the Lighter Elements. N. P. Heydenburg and G. M. Temmer, *DTM, Carnegie Institution of Washington.*—We have obtained thin target excitation curves for gamma-ray emission from low-lying excited states of F^{19},[1] Na^{23}, Mn^{55}, Fe^{57}, and Ge^{73} under alpha-particle bombardment up to 3.5 Mev. In the cases of F^{19} and Na^{23} we also followed the 1.28-Mev and 1.83-Mev gamma rays resulting from the $(\alpha,p\gamma)$ reactions, coming from Ne^{22*} and Mg^{26*}, respectively. Fe^{57} and Ge^{73} were enriched samples (to 59 percent and 78 percent, respectively) obtained from Oak Ridge. All targets were evaporated on thin nickel foil. The $(\alpha,p\gamma)$ reactions give a measure of the compound nucleus formation and show that the targets were thin. We observed the Coulomb and/or inelastic excitation of the 113-kev and 196-kev levels in F^{19}, the 446-kev level in Na^{23}, the 128-kev level in Mn^{55}, the 122-kev line coming from the 136-kev level in Fe^{57}, and a 68-kev line in Ge^{73} (obviously not the 68-kev *M*4 transition which is not seen in the As^{73} decay.[2] The excitation of the reaction gamma rays and the inelastic (Coulomb) gamma rays are strikingly different. The thin target yields are in good agreement with the simple theory of Coulomb excitation for *E*2 transition.[3]

[1] G. M. Temmer and N. P. Heydenburg, Phys. Rev. **93**, 351 (1954); and Phys. Rev. (to be published).
[2] Welker, Schardt, Friedlander, and Howland, Phys. Rev. **92**, 401 (1953).
[3] K. Alder and A. Winther, Phys. Rev. **91**, 1578 (1953).

L6. Photodisintegration of Deuterium by 95-Mev Bremsstrahlung.* Lew Allen, Jr.,† and A. O. Hanson, *University of Illinois.*—Investigation of the deuterium photoeffect has been continued using betatron x-rays of 95-Mev maximum energy. The target volume was defined by tungsten slits. The photoprotons were detected by stacks of 600μ pellicles placed at seven angles between 20° and 160°. Proton energies were determined by range measurements and separated into five energy bins. The statistical error of each differential cross section is less than 10 percent. The curve of total cross section *versus* photon energies between 20 and 65 Mev is in agreement with calculations by Marshall and Guth and Schiff for central forces of 50 percent exchange character. The angular distributions are well fitted by $f(\theta)=(\alpha+\sin^2\theta)(1+2\beta\cos\theta)$, where α varies from 0.12 at 20 Mev to 0.8 at 62 Mev, and β is about $\frac{1}{3}$ (V_P/C).

* This work is supported in part by the joint program of the U. S. Office of Naval Research and the U. S. Atomic Energy Commission.
† Captain, U. S. Air Force, assigned USAF Institute of Technology.

L7. Fine Structure of the $O^{16}(\gamma,n)O^{15}$ Activation Curve.* B. M. Spicer, A. S. Penfold, and J. Goldemberg, *University of Illinois.*—The activation curve has been measured from threshold to 19 Mev by counting the O^{15} positron activity induced in cylinders of compressed boric acid. The curve shows discontinuities in slope at energies 15.60, 15.97, 16.45, 16.68, 16.86, 16.94, 17.04, 17.43, 17.54, 17.66, 17.72, 17.88, 18.48, 18.73, 18.91 Mev. These results will be compared to those of Montalbetti and Katz,[1] who find breaks at 15.6, 15.9, 16.7, 16.9, 17.1, 18.4, 18.7 Mev. The relative positions of these breaks can be reproduced to within ±10 kev. Operating stability of the betatron was often better than ±6 kev, with periodic deterioration to ±30 kev. The absolute energy scale was calibrated by determining thresholds for the $C^{12}(\gamma,n)C^{11}$, $O^{16}(\gamma,n)O^{15}$, $Cu^{63}(\gamma,n)Cu^{62}$ reactions, taken as 18.72, 15.61, 10.65 Mev, respectively, and is believed accurate to ±20 kev. The activation curve was also measured behind 1 electronic absorption length of water. Detailed information will be presented regarding the interpretation of these curves.

* Supported in part by the joint program of U. S. Office of Naval Research and U. S. Atomic Energy Commission.
[1] R. Montalbetti and L. Katz, Can. J. Phys. **31**, 798 (1953).

L8. Photo Protons from Cobalt.* M. E. Toms, H. Gerardo, and W. E. Stephens, *University of Pennsylvania.*—The photoprotons ejected from a 0.7-mil cobalt foil by the bremsstrahlung x-rays from a 24-Mev betatron have been observed in nuclear emulsions. The angular distribution shows a slight forward asymmetry consistent with the results of Mann, Halpern, and Rothman.[1] The energy distribution is consistent with that calculated from an evaporation process. In contrast to copper[2] which has similar thresholds, no evidence was found for photodeuterons. However, there is approximately one photo alpha particle for every 54 photoprotons. Further details will be presented.

* Supported in part by the joint program of the U. S. Office of Naval Research and the U. S. Atomic Energy Commission.
[1] Mann, Halpern, and Rothman, Phys. Rev. **87**, 146 (1952).
[2] Byerly and Stephens, Phys. Rev. **83**, 54 (1951).

L9. The $In^{115}(\gamma,\gamma')In^{115m}$ Cross Section.* J. L. Burkhardt† and E. J. Winhold, *M.I.T.*—The photoexcitation yield of the 4.5 hr isomeric state in In^{115} has been measured at a series of energies from 2 to 14 Mev. Stacked foils were exposed directly in the electron beam from the M.I.T. linear accelerator. A lower limit to the photon absorption cross section is obtained from this measurement. Even though an unknown fraction of the excited nuclei decay to the ground state and are not detected, the experimental data may give an indication of the actual shape of the absorption cross section in the region below particle emission thresholds. The cross section computed from the observed yield curve exhibits a strong maximum at about 8 Mev, as has been reported by others.[1] In the low-energy region the cross section appears to rise continuously, its slope increasing rapidly with increasing energy. At 5 Mev the cross section is about ten percent of the peak value.

* This work was supported by the joint program of the U. S. Office of Naval Research and U. S. Atomic Energy Commission.
† National Science Foundation Predoctoral Fellow.
[1] Goldemberg and Katz, Phys. Rev. **90**, 308 (1953).

L10. Angular Distributions of Photodeuterons.* D. A. Edwards, B. Wolfe, A. Silverman, and J. W. DeWire, *Cornell University.*—The angular distributions of energetic deuterons emitted from various nuclei upon exposure to 300-Mev bremsstrahlung are being investigated, employing a technique reported previously by DeWire, Silverman, and Wolfe.[1] Preliminary results indicate that the angular distributions of deuterons of 40-Mev average energy are roughly the same as those for photoprotons of that energy, for the four elements studied thus far: C, Cu, Ag, and Pb. The ratios of the number of deuterons to the number of protons per unit energy interval at 90° have been measured for Be, Al, Mo, and W in addition to the four elements mentioned in the foregoing. These ratios increase with A from 0.12 for C to 0.24 for Pb (with ten percent statistics); the ratio for Be is 0.21. The

ratios at 90° for C, Cu, and Pb are in agreement with the results reported earlier.[1]

* Supported by the joint program of the U. S. Office of Naval Research and the U. S. Atomic Energy Commission.
[1] DeWire, Silverman, and Wolfe, Phys. Rev. **92**, 519 (1953).

L11. Systematics of Photoproton Yields. E. V. WEINSTOCK AND J. HALPERN, *University of Pennsylvania*.—The photoproton yields from the elements Ta, Pt, Pb, W, and Au have been determined for betatron bremsstrahlung bombardment at 22-Mev peak energy by the use of zinc sulfide detectors[1] and a 50-μsec betatron pulse duration. The yields, as measured in photoprotons per mole per roentgen, are as follows: Ta, 5.7×10^4; Pt, 2.9×10^4; Pb, 5.8×10^4; W, 5.2×10^4; and Au, 1.9×10^4. These values, along with previous determinations,[1] permit a study of general behavior of photoproton yields for Z values throughout the periodic table. Comparisons with calculations based on the evaporation model[2] show good agreement with experimental trends up to a Z of 50, after which the measured yields are too high by factors ranging from 10 to 10^4. Calculations based on the direct photoelectric process[3] give better agreement, though still too low by a factor of 10.

[1] A. K. Mann and J. Halpern, Phys. Rev. **82**, 733 (1951).
[2] J. M. Blatt and V. F. Weisskopf, *Theoretical Nuclear Physics* (John Wiley and Sons, Inc., 1950), pp. 340–79.
[3] E. D. Courant, Phys. Rev. **82**, 703 (1951).

L12. Energy Dependence of Some Photonuclear Reactions.* T. T. SUGIHARA† AND I. HALPERN,‡ *M.I.T.*—The relative yields of some selected radionuclides formed by the irradiation of arsenic with 140-Mev and 320-Mev bremsstrahlung have been measured. Radiochemical isolation of Ga, Cu, Ni, and Co, as well as an aliquot of the arsenic target, led to the following relative yields at 140 Mev and 320 Mev, respectively: As^{74}, 1050, 1050; As^{72}, 110, 110; Ga^{72}, 0.3, 0.5; Ga^{72}, 0.9, 1.2; Ga^{70}, 8.4, 9.5; Ga^{68}, 4.2, 7.6; Ga^{66}, 0.2, 0.7; Cu^{67}, 0.1, 0.2; Cu^{64}, 0.3, 2.5; Cu^{61}, <0.1, 0.6; Ni^{65}, <0.02, 0.05; Ni^{65}, 0.08, 0.1; Co^{61}, 0.09, 0.2; Co^{55}, <0.02, 0.1. Irradiations were monitored with Cu foil and yield values are relative to the saturation Cu^{64} activity produced in the foil. As the maximum energy of the synchrotron is reduced, the yields of nuclides far from the target are decreased. The isotope of maximum yield for a given Z seems to shift to the neutron-rich side at the lower energy. This may be related to increased α emission at lower energy. The difference in yields at the two energies and the difference bremsstrahlung spectrum suggest that the major contribution to the 320-Mev yields of copper, and probably those of lower Z, comes from quanta of energy greater than 140 Mev.

* Supported in part by the U. S. Atomic Energy Commission.
† Now at Department of Chemistry, Clark University.
‡ Now at Department of Physics, University of Washington.

FRIDAY MORNING AT 9:30

Sheraton Park, Caribar Room

(F. J. DYSON presiding)

Theoretical Physics, III: Field Theory

M1. Electromagnetic Interaction of Particles of Spin ½. SURAJ N. GUPTA, *Purdue University* (introduced by F. J. Belinfante).—It is well known that if we consider the interaction of charged particles of spin 0, ½, and 1 with the electromagnetic field, the divergencies in the case of spin ½ are less severe than those in the case of spin 0 or 1. In fact, confining ourselves to mass and charge (or field strength) renormalizations, we can remove all the divergencies only in the case of charged particles of spin ½. Since it is not known what the situation is for any other particles of half-integral spin, we have investigated the interaction of charged particles of spin ½ with the electromagnetic field. We have used the Fierz-Pauli theory for a field of spin ½, and it is found that the quantization of such a field can be carried out without any special difficulty. It is also possible to obtain the usual rules for the contribution of any Feynman diagram in this case. A preliminary investigation shows that the divergencies in this case are even stronger than those in the case of charged particles of spin 1.

M2. Quantized Linear Theory of Gravitation. I. F. J. BELINFANTE AND J. C. SWIHART, *Purdue University*.—We have quantized the Lorentz-covariant linear gravitational theory reported on earlier,[1] with choice of constants $b=q=0$, $C=1$, while the coefficients $a, f=-\xi a$, and K provisionally are arbitrary. The Lorentz-covariance of the canonical commutation relations has been proved by considering infinitesimal Lorentz transformations. As our old choice of the Lagrangian density would make the interaction part of the energy density T^{00} non-Hermitian, we must introduce new variables by a canonical transformation before an interaction representation can be defined. We have found appropriate new canonical variables for ψ and for the canonical conjugates of $h_{\lambda\mu}$. After expressing T^{00} in the new variables, its interaction part becomes hermitian. Also, the old expression $\psi\dagger(1+\frac{1}{2}h_{0\mu}\alpha^\mu)\psi$ for the probability density, when expressed in the new variables, becomes simply $\psi\dagger\psi$. While the new ψ is no undor[2] in Heisenberg representation, the new and not the old ψ becomes an undor in the interaction representation. We are now proving the integrability of the generalized Schroedinger equation for this interaction representation.

[1] Abstracts, Phys. Rev. **90**, 357 and **91**, 500 (1953).
[2] F. J. Belinfante, Physica **6**, 849 (1939).

M3. Quantized Linear Theory of Gravitation. II.* J. C. SWIHART AND F. J. BELINFANTE, *Purdue University*.—We perform another canonical transformation, from the $h_{\mu\nu}$ variables and their canonical conjugates $p^{\mu\nu}$ to new canonical variables (no tensors) $y_{\mu\nu}$ and $z_{\mu\nu}$, by $y_{00}=-\frac{1}{2}h_\nu{}^\nu$, $y_{jj}=-h_{jj}+h_{00}+\frac{1}{2}h_\nu{}^\nu$, $y_{\mu j}=h_{\mu j}$, $(j=1,2,3;\ \mu,\nu=0,1,2,3;\ \mu<j;\ z_{\mu\nu}$ in terms of $p_{\mu\nu}$ similarly). The Fourier coefficients of $y_{\mu\nu}$ and $z_{\mu\nu}$ are expressed in terms of annihilation operators $a_{\mu\nu}(\mathbf{k})$ and their conjugates. With z axis $\|\mathbf{k}$ we introduce $b_{11}=(a_{11}-a_{22})/\sqrt{2}$, $b_{22}=(a_{11}+a_{22})/\sqrt{2}$, further $b_{\mu\nu}=a_{\mu\nu}$, and occupation numbers $n_{\mu\nu}(\mathbf{k})=b_{\mu\nu}{}^*b_{\mu\nu}$. An auxiliary condition $(\nabla_\nu h_\mu{}^\nu+R\nabla_\mu h_\nu{}^\nu)^{(+)}\Psi=0$ is postulated for eliminating negative energies from $H_g=\Sigma_{\mathbf{k}}\hbar ck[\Sigma_{(j\le1)}n_{jl}(\mathbf{k})-\Sigma_\mu n_{0\mu}(\mathbf{k})]+$constant. Thence $\langle n_{13}\rangle-\langle n_{01}\rangle=\langle n_{23}\rangle-\langle n_{02}\rangle=\langle n_{33}\rangle-\langle n_{03}\rangle=0$ for a Gupta metric, while $\langle n_{33}\rangle-\langle n_{00}\rangle=0$ if $(1+4R)^3=4\xi-1$. As $T^{\mu\nu}$ in general does not satisfy the corresponding conservation law, Ψ in the auxiliary condition must be taken in Heisenberg while $h_\mu{}^\nu$ in interaction representation. The condition is thus imposed on incident gravitons only. A static central gravitational field yet satisfies it, if $\alpha=\frac{1}{4}$ (thence deflection of light along sun 1.75″),

and if $\xi=\frac{1}{2}-4K+16K^2$, $R=2K-\frac{1}{2}$. With $K=1/16$ this would yield Einstein's values for the observable effects.

* Supported in part by National Science Foundation.

M4. Quantum Theory of Gravitation.* PETER G. BERGMANN, *Syracuse University.*—Once the equations of the gravitational field have been cast into the canonical form, their actual quantization may be attempted with the help of standard perturbation theory, in order to answer such questions as the collision cross section for two gravitons. Unfortunately, the Hamiltonian is of infinitely high degree in the field variables, and so it would seem as if a time-dependent theory should lead to an infrared catastrophe even in a first-order calculation. It now appears as if the adoption of a particular set of coordinate conditions would reduce the Hamiltonian to a polynomial, albeit of a very high degree. For instance, there are first-order processes that involve in a single collision two photons and six gravitons. In purely gravitational interactions a first-order process may involve as many as eleven gravitons. It may be possible to reduce these figures further by additional transformations, but they show at least that first-order processes involving infinite numbers of gravitons may be completely eliminated.

* Research supported by the U. S. Office of Naval Research.

M5. Decay of Gravitons. J. GARDNER* AND J. BUNBURY,† *Deep River, Ontario.*—In seeking a unified theory of nuclear, electromagnetic, and gravitational phenomena we compare the fundamental particles[1] of these respective fields: pions, photons, and gravitons are all bosons having spins 0,1,2, respectively,[2] and the first two named "decay" into fermions of half-integer spin and having no direct interaction with the fundamental fields. If gravitons also decay we might by analogy expect the decay products to be fermions (e.g., neutrinos or anti-neutrinos) having no direct interaction with the gravitational field. Just as in the case of pair‡ creation, a certain threshold energy is required for graviton decay. It is estimated that this is never reached in terrestrial gravitational fields but may well occur in the intense gravitational fields of certain stars.

* Gravity Foundation Traveling Fellow.
† Deceased.
[1] E. E. Witmer, Phys. Rev. **87**, 237 (1952); Bull. Am. Phys. Soc. **29**, No. 1, 27 (1954).
[2] J. Talhausen and U. Schmalhausen, Suppl. J. Exptl. Theoret. Phys. U.S.S.R. **21**, 99 (1950).
‡ The authors wrote "pear." The alteration here made may be unjustified.

M6. Hyperquantization of Feynman Amplitudes. F. COESTER, *The Institute for Advanced Study.*—Mathews and Salam[1] and Freese[2] have studied differential equations for Feynman amplitudes which follow from the field equations and a suitable formal definition of the amplitudes in terms of Heisenberg fields. These equations can be cast into an extremely simple form by a hyperquantization procedure which leads to an occupation number representation for the set of all Feynman amplitudes. The relation between the amplitudes and the occupation number representation is quite similar to that between the Fock amplitudes and the occupation number representation commonly used in field theory. Formal solutions of the new equations will be given which can be renormalized explicitly. The well-known results of perturbation theory as well as the integral equations for the amplitudes can be easily derived from these formal solutions.

[1] P. T. Mathews and A. Salam, Proc. Roy. Soc. (London) **221**, 128 (1954).
[2] E. Freese, Z. Naturforsch. **8a**, 776 (1953).

M7. Isotopic Spin Conservation and a Generalized Gauge Invariance.* C. N. YANG† AND R. MILLS, *Brookhaven National Laboratory.*—The conservation of isotopic spin points to the existence of a fundamental invariance law similar to the conservation of electric charge. In the latter case, the electric charge serves as a source of electromagnetic field; an important concept in this case is that a gauge invariance which is closely connected with (1) the equation of motion of the electromagnetic field, (2) the existence of a current density, and (3) the possible interactions between a charged field and the electromagnetic field. We have tried to generalize this concept of gauge invariance to apply to isotopic spin conservation. It turns out that a very natural generalization is possible. The field that plays the role of the electromagnetic field is here a vector field that satisfies a nonlinear equation even in the absence of other fields. (This is because unlike the electromagnetic field this field has an isotopic spin and consequently acts as a source of itself.) The existence of a current density is automatic, and the interaction of this field with any fields of arbitrary isotopic spin is of a definite form (except for possible terms similar to the anomalous magnetic moment interaction terms in electrodynamics).

* Work performed under the auspices of the U. S. Atomic Energy Commission.
† On leave of absence from the Institute for Advanced Study, Princeton, New Jersey.

M8. Conservation Theorems in Modified Electrodynamics.* J. W. DETTMAN AND A. SCHILD, *Carnegie Institute of Technology.*—A system of interacting particles with variable rest masses is considered,[1] whose motion is governed by a variational principle of the form

$$\delta\tfrac{1}{2}\sum_{ab}\int_{-\infty}^{\infty}\int_{-\infty}^{\infty}\Lambda(\xi_{ab}{}^{\mu},\dot{x}_a{}^{\mu},\dot{x}_b{}^{\mu})du_a du_b=0. \tag{1}$$

Here $x_a{}^{\mu}$ are the space-time coordinates of particle a, $\xi_{ab}{}^{\mu}=x_a{}^{\mu}-x_b{}^{\mu}$, $\dot{x}_a{}^{\mu}=dx_a{}^{\mu}/du_a$, and u_a is a physically significant parameter along the world line of a, the variable rest mass m_a being defined by $m_a{}^2=\dot{x}_a{}^{\mu}\dot{x}_{a\mu}$. For suitable choices of the interaction function Λ, it has been shown[1] that, when the particles are at distances large compared to the classical electron radius, the new theory reduces to classical electrodynamics, and that the variable rest masses m_a become constants of motion. The conservation laws of energy-momentum and of angular momentum for systems governed by (1) are derived from the Lorentz invariance of Λ.

* Assisted by Air Research and Development Command, U. S. Air Force.
[1] A. Schild, Phys. Rev. **92**, 1009 (1953).

M9. Variance Properties of a General Field Operator. P. H. FANG, *Catholic University of America.*—Consider a class of operator functions $S(x,p)$, $[p=-i(\partial/\partial x)]$, which satisfies the following equation under a transformation operator T, $TS(x,p)=tS(x,p)$; here t is the eigenvalue of T; in this case, S is called t-variant. In particular, when $t=1$, one has invariance, a condition usually required in ordinary quantum mechanics for certain T's. Four types of transformation are studied, namely, the Lorentz transformation T_L, the Hermitian transformation T_H, the Fourier transformation T_F, and the reciprocity transformation T_R. In the case of T_F, $T_F{}^4=1$, and $t_F=\pm1, \pm i$. The connection of t_F with t_L, t_H, and t_R is established, from which, respectively, the character of the light cone, the property of eigenvalue of $S(x,p)$, and the connection of $S(x,p)$ in the space-time space and momentum-energy space is obtained. Yukawa and Rayski's nonlocal field theory and Born's mass-spectrum problem of elementary particles are considered in relation to this larger class of transformations.

M10. Superselection Rule Regarding Spinor Particle Numbers. SATOSI WATANABE, *U. S. Naval Postgraduate School.*—Consider a unitary transformation U which transforms the state function Ψ into $U\Psi$ and all physical quantities Q (including interaction Hamiltonian) into UQU^{-1}. If the interaction type is such that the total number of spinor particles (which may or may not belong to the same field) can change only by an integral multiple of an integer n, then we have $UQU^{-1}=Q$ if we take $U=U_n=\Pi_s{}^{\infty}(1-N_s+\omega_n N_s)$

$=\Pi_i{}^{\otimes}\omega_n{}^{N_i}$. N_i is the particle number operator of eigenstate i of the spinor fields, and ω_n is any one of the nth roots of unity. Then, Ψ and $U\Psi$ are physically indistinguishable from each other, whatever physical quantities may be used for the intended detection. If we take $\omega_n=\exp(2\pi i/n)$, the eigenvalues of U_n become n different nth roots of unity, thus dividing the entire Hilbert space into n disconnected subspaces. On account of Lorentz invariance, n is limited to even numbers. Thus W.W.W.'s superselection rule[1] ($n=2$) has a general validity. W.W.W.'s original proof is based on a particular situation: $R^TR^{-1}=U_2$.[2] In case $n=0$ (heavy particles?), the superselection rule with any arbitrary n will hold.

[1] Wick, Wightman, and Wigner, Phys. Rev. **88**, 101 (1952).
[2] See Eq. (8.15), S. Watanabe, Phys. Rev. **84**, 1008 (1951).

M11. Invariance and Isotopic Spin. A. W. STERN, *Flushing 56, N. Y. C.*—A recent attempt to incorporate the concept of isotopic spin into the formalism of a consistent theory instead of using this concept as a shorthand way of distinguishing between the neutron and proton states of the nucleon has been made by Pais. His work employs a six-dimensional manifold, that is, it involves the familiar space time of four dimensions *plus* an isotopic spin or ω space of two dimensions. The six dimensions are not all on an equal footing. There are phenomena, electromagnetic and Coulomb interactions, which are functions of the space-time variables but not of the ω variables. Thus we have two different kinds of space, which is a way of introducing heterogeneity in the continuum. There is an infinite number of particle states in the mass spectrum of Pais' new theory. Although they are extremely short-lived, some of the mass states may nevertheless manifest themselves in very high-energy scattering and particle production phenomena. Selection rules, symmetry principles, and invariant properties are absolute only in the simplest and isolated systems, and may be violated in the presence of perturbing fields. They are only relative in complex systems, such as a system which would embrace nucleons, π mesons, and the light particles all together.

M12. On the Formulation of Quantum Electrodynamics in Minkowski Space. T. A. WELTON, *Oak Ridge National Laboratory.*—A formulation of quantum electrodynamics has been found which is completely analogous to the elementary nonrelativistic quantum mechanics. A study is made of a hypothetical system of particles moving in a Minkowski space of four completely equivalent dimensions, with a fifth variable analogous to the time in nonrelativistic calculations. The particles move only under the action of external forces, which, however, are specified by certain noncommuting amplitudes. Mass values and transition probabilities, as well as wave functions, although noncommuting quantities, are simply calculated by the methods of elementary wave mechanics. To obtain physical answers, appropriate averages must first be taken of the noncommuting preliminary answers, and a simple analytic continuation must be performed in which the real mass constant for the hypothetical particles is made purely imaginary. In this way a one-to-one correspondence is established between the results of calculations in the hypothetical space and actual physical phenomena. All elementary results agree completely with those of conventional formulations. The description of pair production is thus far ambiguous, but results of a promising formulation will be presented. Relativistic corrections to the Lamb shift have also been calculated and will be presented. These differ essentially from previous calculations.

M13. Properties of Hypothetical Atoms Composed of Magnetic Poles. ARTHUR E. RUARK, *University of Alabama.*—There is need for some numerical discussion of the properties of hypothetical atoms, presumably unstable, composed of monopoles. In order to assess the possibility of detecting such entities, in case they exist, attention will be given to the Dirac type and to poles having strength g equal to the electron charge. See also the abstract of a talk before the 1954 meeting of The Southeastern Section, in which the latter monopole type is discussed on the basis of generalized electromagnetic equations symmetrical in respect to charges and poles.

M14. A Completed Quantum Theory. IRVING STEIN, *Wayne University.*—Preliminary work has been completed on a modified quantum theory, from which the standard theory can be derived and in which there is no indeterminacy. The modified theory is based upon the assumption that the state vectors associated with given particles actually describe the kinematical and dynamical properties of the particles. It is then found that the classical kinematical variables are generally not appropriate as quantum-mechanical kinematical variables. Based upon the assumed reality of the state vectors, it is found that the observables of Dirac are the quantum-mechanical variables. Three further postulates are made: (1) each particle has simultaneously a value of every state vector permitted by the field and therefore also of every associated observable, each a kinematical degree of freedom of the particle. (2) The time-dependent Schroedinger equation holds for each of the state vectors. (3) The state vectors are all related to each other by a measure. The measure of the 'distance' of the state vectors is given by the angle in Hilbert or function space between one state vector and the conjugate of the other state vector. Thus, the kinematical variables are not independent variables since they are related to each other through the statistics of the standard theory. The theory is a field theory of kinematical variables.

FRIDAY AFTERNOON AT 2:00

Shoreham, Main Ballroom

(E. O. HULBURT presiding)

Invited Papers in Nuclear Physics

N1. Experimental and Theoretical Studies of Levels in Lead 206. D. E. ALBURGER, *Brookhaven National Laboratory.* (30 min.)

N2. Recent Progress in Microtron Research. H. F. KAISER, *Naval Research Laboratory.* (30 min.)

N3. Classical Field Theory of Nuclei. EDWARD TELLER, *University of California, Berkeley.* (45 min.)

FRIDAY AFTERNOON AT 2:00

NBS, East Building

(A. V. ASTIN presiding)

Invited Papers in General and Low-Temperature Physics

O1. Recent Determinations of the Velocity of Light. HAROLD LYONS, *National Bureau of Standards.* (30 min.)

O2. Electron-Diffraction Studies of Internal Motion in Molecules. I. L. KARLE, *Naval Research Laboratory.* (30 min.)

O3. Atomic Theory of the Lambda Transition in Liquid Helium. D. TER HAAR, *St. Andrews University, Scotland.* (30 min.)

O4. Superconducting Compounds. B. T. MATTHIAS, *Bell Telephone Laboratories.* (30 min.)

O5. Magnetic Measurements Below 1° Kelvin. R. P. HUDSON, *National Bureau of Standards.* (30 min.)

FRIDAY AFTERNOON AT 2:00

NBS, Materials and Testing

(H. D. HAGSTRUM presiding)

Electrostatic and Electron Physics

OA1. A New Technique for Solving Three-Dimensional Electron Optics Potential Problems with Axial Symmetry. JENNY E. ROSENTHAL, *Du Mont Laboratories.*—The need for a new approach for solving 3-dimensional potential problems is discussed since standard techniques of separating variables and then expanding the solution in terms of products of known functions cannot be applied—even in principle—to many cases of boundary value problems with discontinuous boundaries. It is shown that methods based on complex potential can be extended from ordinary 2-dimensional problems to 3-dimensional problems with axial symmetry. Such an extension suggests a different type of expansion for the potential function satisfying Laplace's equation in cylindrical coordinates. This expansion has the advantage that every term in it has the proper behavior at infinity, i.e. (in the usual notation), goes to zero as $C\{Z^2+r^2\}^{-\frac{1}{2}}$. Special cases are considered and the possibility is discussed of using them to build up solutions of more difficult problems.

OA2. An Automatic Electrostatic Field Plotter. DAVID H. ANDREWS, *U. S. Naval Materiel Laboratory* (introduced by Robert J. Wohl).—Rapid electrostatic field plots are automatically made using the resistive paper technique combined with a commercial "$X-Y$" recorder, providing easily and quickly a graphic presentation of the equipotential lines for any desired electrode configuration. Experimental verification of its accuracy is shown by a comparison of the equipotential lines drawn by this plotter with those obtained from an electrolytic tank. The underlying principles for modification of an "$X-Y$" recorder to accomplish this purpose are stated and details given for the particular recorder used. A description of the techniques used in the preparation of the sample electrode systems and in the operation of the plotter is given. Several illustrative field plots are shown together with the application of the plotter to a typical cathode-ray tube electron gun.

OA3. Excitation and Separation of Pure High-Order Modes in Large High-Q Cavities. C. T. ZAHN AND W. G. SCHWEITZER, JR., *National Bureau of Standards.*—A successful method for suppressing undesired modes is presented. It is based on mathematical properties of the wave equation: (1) particular solutions extend analytically throughout all space, and (2) nodal surfaces divide space into elementary cells. Each particular, or "master" mode pattern thus defines an infinite variety of cavities having a common frequency, namely, all those corresponding to the addition of adjacent cells. These principles can be used to great advantage in microwave techniques. By suitable choice of "complex cavity", devices can be obtained with remarkable transducing, filtering, or suppressing properties. Such complex cavity-systems are amenable to extraordinarily simplified theoretical calculations. By an experimental application of the foregoing ideas to a cylindrical system it was possible to excite a very large cavity in a *well-separated* axially symmetric transverse electric mode of frequency 20 000 megacycles per second, and having about 50 radial nodes and 100 longitudinal. The *observed* Q was slightly less than *one million.*

OA4. Time Delay in Secondary Emission.* M. H. GREENBLATT, *RCA Laboratories.*—An experiment to measure the time delay in secondary emission in as direct a manner as possible was performed. The experiment consists of producing short bursts of primary electrons, allowing these primaries to strike a secondary emission target, and examining the resultant bursts of secondary electrons. The short primary pulses are produced by deflecting an electron beam at 400 mc across a circular aperture. The electrons that get through bombard a secondary emissive surface. The bursts of secondaries are analyzed by synchronously deflecting them across a fluorescent screen or presentation electrode. The time dispersion of the secondary pulse is thus made to correspond to an intensity modulation on the face of the tube. The measurements show that any broadening of the primary pulse by the secondary emission process is less than 7×10^{-11} sec and is probably much less.

* Work supported by U. S. Atomic Energy Commission.

OA5. Forward-Backward Ratio of Secondary Emission Produced by 1.3-Mev Electrons.* M. A. POMERANTZ, J. F. MARSHALL, AND R. A. SHATAS, *Bartol Research Foundation.*—A new method for measuring the secondary-electron emission from thin targets bombarded by energetic electrons permits

the independent determination of the yield from both faces of the target foil through which the primary electrons pass with negligible energy loss. The experimental arrangement comprises essentially a sandwich consisting of the target interposed between a pair of closely spaced thin metallic foils, the electrostatic potentials of which can independently be defined. From various combinations of the 9 equations relating the 9 observed target currents to the corresponding potential configurations, the yields from the two faces of the specimen can be determined. Such an analysis in the case of a 11 mg/cm² Ni target provides a value for the ratio of the yield in the forward direction (i.e., same as incident beam) to that in the backward direction, $\delta_F/\delta_B = 1.05 \pm 0.13$, where the indicated uncertainty is inherent in the present method of measuring currents. Although the targets were only chemically cleaned, this result was unaffected by interchanging front and back surfaces by a rotation of the sandwich in vacuum.

* Assisted by the U. S. Office of Naval Research and by the U. S. Office of Ordnance Research.

OA6. Target-Thickness Dependence of Delta-Ray Emission Produced by 1.3-Mev Electrons.* J. F. MARSHALL, R. A. SHATAS, AND M. A. POMERANTZ, *Bartol Research Foundation.*—The yield of energetic secondaries (delta rays) emitted from thin foils bombarded by 1.3-Mev electrons has been determined as a function of target thickness for Al and Ni in the range 2 mg cm^{-2} to 70 mg cm^{-2}, the upper limit being imposed by uncertainties introduced by the stopping of multiply-scattered primaries. In accordance with expectation, the yield increases with thickness from 0.5 percent to 2 percent in the case of Al of the aforementioned thicknesses. On the basis of the assumption that the lattice electrons can be regarded as free in the present analysis, and by invoking a range-energy relationship for treating the escape of the delta-rays, the yields have been computed. The theoretical absolute values are only slightly higher than the experimental results, and the observed data are in good agreement with the shape of the calculated yield *vs* thickness curves. Furthermore, the difference in yields per mg cm^{-2} of Al and Ni is in accord with theory, as is the similarity between Ni and Cu.

* Assisted by the U. S. Office of Ordnance Research and by the U. S. Office of Naval Research.

OA7. Characteristic Energy Loss of Electrons.* LEWIS B. LEDER AND L. MARTON, *National Bureau of Standards.*—Measurement of the energy loss of 30–35 kev electrons in solids reported at the last New York meeting[1] has been continued. Energy loss values obtained for several new materials will be reported. In particular, comparison will be made of the characteristic energy losses for metals and the metal compounds. Also, the apparatus has since been improved so that we can now measure not only the energy loss spectra, but also relative intensities and cross sections for the events.

* This work was supported by the U. S. Office of Naval Research.
[1] Lewis B. Leder and L. Marton, Bull. Am. Phys. Soc. **29**, No. 1, 40 (1954).

OA8. Electron Scattering in Solids at 20 kev,* L. MARTON, TOMMY F. MCCRAW, AND J. AROL SIMPSON, *National Bureau of Standards.*—The apparatus for measuring large-angle scattering of electrons described at an earlier meeting[1] has been made automatic. Energy and intensity spectra at angular intervals of 0.002 radians are measured in two seconds by sweeping the scattered electron beam magnetically. A complete run over 30 degrees can be made in eight minutes. Intensity and energy distributions have been obtained for several metals, in some cases through an angle of 30 degrees.

* This work was supported by the U. S. Office of Naval Research.
[1] L. Marton, Phys. Rev. **87**, 200(A) (1952).

OA9. The Phenomena of Plasma Resonance.* K. S. W. CHAMPION AND S. C. BROWN, *M.I.T.*—Plasma resonance is associated with the transmission of externally applied high-frequency electromagnetic waves through a plasma. Two types of resonance will be discussed. The first, impedance resonance, occurs when the E field at a point has a relative maximum. The second, dielectric resonance, occurs when the dielectric constant is zero at the point considered. Impedance resonance occurs when $ne^2/m\epsilon_0\omega^2 = 1$ and dielectric resonance when $ne^2/m\epsilon_0(\nu_c^2+\omega^2) = 1$, where n represents the electron density and ν_c the electron collision frequency. At low pressures, when $\nu_c^2 \ll \omega^2$, the two types of resonance coincide, but they differ at high pressures. Impedance resonance corresponds to greatest ionization and excitation rates. Above dielectric resonance the transmitted electromagnetic waves are strongly attenuated and there is a reflected wave. A special tunable 100 Mc/sec resonant cavity was designed so that discharges above plasma resonance could be produced in relatively large volumes. Discharges were obtained which, under the appropriate conditions, exhibited the properties of impedance and dielectric resonance.

* This work was supported in part by the Signal Corps, the Air Materiel Command, and the U. S. Office of Naval Research.

OA10. Magneto-Hydrodynamic Flows in Hydrogen and Helium.* W. R. ATKINSON, R. G. FOWLER, AND W. R. HOLDEN, *University of Oklahoma.*—An electrically energized shock tube was used to produce a stream of luminous conductive gas. Two aspects of the interaction between this flow and a stationary magnetic field were observed. First, eddy currents induced in the moving plasma produced a field that augmented the static field in the region ahead of the advancing ion front. The resulting field can be described as similar to the static field except that each line of force is pushed downstream by the advancing ion front which resists penetration by the field to an extent determined by the conductivity. This field alteration was studied by observing the voltage induced in external coils. Secondly, alterations in the flow produced by the field were studied by a rotating mirror. Again plasma eddy currents opposed relative motion between the field and the plasma which consequently lost flow energy and gained heat energy that increased the luminosity. This attenuation of flow velocity at times produced a receding shock originating at the boundary of the magnetic field. Further experiments indicated that expansion in the shock tube may be influenced by the inherent magnetic fields of the initial heating current.

* This work was supported by the U. S. Office of Naval Research.

OA11. Motion of Arc Cathode Spot in a Magnetic Field. ROBERT M. ST. JOHN AND J. G. WINANS, *University of Wisconsin.*—The retrograde motion of the cathode spot of an arc in a transverse magnetic field[1] can be associated with electrostatic forces on positive ions produced by electron impact. A cathode spot assembly consisting of a group of electrons in the cathode, a positive ion sheath separated by a dark space from the cathode, and an electron cloud between the positive ion sheath and anode is postulated. Electrons after acceleration through the cathode dark space would travel a curved path due to the magnetic field and produce new positive ions on the forward (direction of magnetic force) side of the cathode spot. These new positive ions would be attracted by the cathode spot assembly with a resultant force that would cause them to overshoot the positive ion sheath before being pulled into the cathode to start a new spot in the retrograde direction. Addition of an inert gas reduces the mobility of positive ions to the order of that of the cathode electrons thus permitting forward motion of the cathode spot assembly to reduce the overshooting. Higher pressures would cause a forward spot motion.

[1] J. D. Cobine and C. J. Gallagher, Elec. Eng. **68**, 469 (1949).

OA12. An Electron Spectrometer for the Study of Inelastic Collision Cross Sections.* E. N. LASSETTRE, A. S. BERMAN, S. SILVERMAN, AND M. E. KRASNOW, *The Ohio State University.*—An electron spectrometer, an improved version of an instrument previously used in this laboratory, is described which is suitable for the determination of electron impact energy spectra and relative electronic collision cross sections. A velocity analyzer of the type described by Yarnold and Bolton,[1] with a resolving power of 2500, is employed. Scattered current is detected by a particle counter of the electron multiplier type developed by J. S. Allen.[2] The instrument has been used in the study of inelastic collision cross sections at scattering angles above 3.5°, incident kinetic energies of 400–600 ev, and excitation energies less than 80 ev. Cross sections are placed on an absolute basis by comparing the scattering with that for the $1^1s \rightarrow 2^1P$ transition in helium and using the theoretical cross sections (unpublished calculations by Lassettre and Jones) for the helium scattering. The construction, operation, and capabilities of the above instrument will be discussed.

* The research reported in this paper has been sponsored by the Geophysics Research Directorate of the Air Force Cambridge Research Center, Air Research and Development Command.
[1] G. D. Yarnold and H. C. Bolton, J. Sci. Instr. Britain **26**, 38 (1949).
[2] J. S. Allen, Rev. Sci. Instr. **18**, 739 (1947).

OA13. Electronic Collision Cross Sections and Oscillator Strengths for Oxygen in the Schumann-Runge Region.* E. N. LASSETTRE, S. SILVERMAN, AND M. E. KRASNOW, *The Ohio State University.*—Using the apparatus and techniques described in a concurrent abstract the electronic collision cross sections for the energy loss range 6.5 to 10.7 electron volts in oxygen have been determined. In this region the spectrum has two peaks, one at 8.44 electron volts, corresponding to the Schumann-Runge continuum, and the other at 9.94 electron volts. Electronic collision cross sections were determined for the peak at 8.44 volts for angles ranging from 3.5 to 9.5 degrees with incident electron energies of 519 and 611 volts, and for the 9.94-volt peak from 3.5 to 8 degrees with an incident electron energy of 518 volts. From these data generalized oscillator strengths have been calculated, and extrapolated to give optical oscillator strengths. For the 8.44-volt peak the differential optical oscillator strength obtained in this way is 0.17, and the integrated optical oscillator strength from 6.5 to 9.3 volts is 0.23. For the 9.94-volt peak the differential optical oscillator strength is 0.038 and the integrated optical oscillator strength is 0.025. The results for the 8.44-ev transition will be compared with the optical determinations on the Schumann-Runge continuum.

* The research reported in this paper has been sponsored by the Geophysics Research Directorate of the Air Force Cambridge Research Center, Air Research and Development Command.

OA14. Scattering of H^- Ions in the Range 20–400 ev.* E. E. MUSCHLITZ, JR., *University of Florida.*—A new ion source designed for the production of negative ions coupled with a 90° mass spectrometer has been utilized for obtaining beams of negative ions. Collimated beams of H^- ions, 2 mm in diameter and with intensities up to 10^{-12} ampere, have been obtained. Differential pumping and electrostatic focusing have been employed in the same manner as in previous work with positive ion beams.[1] Scattering cross sections have been determined for collisions of H^- ions in hydrogen at pressures of 10^{-1} to 10^{-3} mm Hg using the method of Simons and co-workers.[2]

* Supported by U. S. Office of Naval Research.
[1] Simons, Francis, Fontana, and Jackson, Rev. Sci. Instr. **13**, 419 (1942).
[2] Simons, Muschlitz, and Unger, J. Chem. Phys. **11**, 307 (1943).

OA15. Experimental Determination of Charge Transfer Cross Sections. W. F. SHERIDAN AND J. A. DILLON, JR., *Air Force Cambridge Research Center,* AND S. N. GHOSH,* *Wentworth Institute.*—Cross sections for charge transfer reactions between ions and neutral atoms and molecules have been measured in the energy range from 50 to 850 ev. The ion source and collimator consists of a modified Bennett-type mass spectrometer, and the collection chamber is similar to that used by Keene.[1] Cross sections for symmetrical reactions involving noble gases are in good agreement with previously reported values. The values for helium are of the same magnitude as those of Hasted[2] and others rather than the higher values obtained by extrapolating the results of Keene and Meyer. For N_2^+, N_2, and N_2^+, A reactions, cross sections are generally larger than those for O_2^+, O_2, and O_2^+, A reactions in agreement with predictions based on the Frank-Condon principle.

* Part of this research was supported by the Geophysics Research Directorate, Air Force Cambridge Research Center, Air Research and Development Command.
[1] J. P. Keene, Phil. Mag. **40**, 369 (1949).
[2] J. B. Hasten, Proc. Roy. Soc. (London) **A205**, 421 (1951).

FRIDAY AFTERNOON AT 2:00

Sheraton Park, Continental Room

(L. R. HAFSTAD presiding)

Neutron Physics, I: Neutron Scattering

P1. A System for Measuring Flight Times of Fast Neutrons. CONWAY W. SNYDER AND VINCENT E. PARKER,* *Oak Ridge National Laboratory.*—For determining the energies of neutrons from nuclear reactions and scattering, a flight-time apparatus has been built. Neutrons are produced in pulses 10 millimicroseconds or less in length by sweeping the ion beam one million times per second past a slit ahead of the neutron-producing target, and are detected by a liquid scintillator and photomultiplier at a distance of one to ten meters. Current pulses from the target and photomultiplier pulses are amplified, equalized, clipped, and fed into a 1*N*26 crystal diode which acts as a fast coincidence circuit. Flight times are measured by inserting lengths of coaxial cable in the neutron detector channel to obtain coincidence. A subsequent slow coincidence can also be used to permit pulse-height selection of the photomultiplier pulses. Preliminary tests with neutrons produce in *d-n* and other reactions indicate that the flight times of monoenergetic neutrons can be measured to better than 5 millimicroseconds.

* Research Participant from Louisiana State University.

P2. Time of Flight Measurements of Inelastic Neutron Scattering. GERARD K. O'NEILL, *Cornell University.*—With a technique which has been described previously,[1] the energy distributions of neutrons inelastically scattered from 14.6 Mev by C, Al, Cu, Sn, and Pb have been measured. Three-point angular distributions for the process in C, Al, and Pb were also obtained. 14.6-Mev $T(d,n)\alpha$ neutrons, whose direc-

tions and origin times were obtained from their accompanying alphas, scattered in a thin slab. Scattered neutrons above 0.5 Mev were detected after traversing 50 to 100 cm, and their flight times were measured by a direct-reading analyzer having nine 4.6 millimicrosecond channels. Working distance was limited by scatterer-in backgrounds, scatterer-out background exceeding 20 percent only for light elements. The over-all resolution was 0.25 Mev at 1 Mev, 1 Mev at 2.5 Mev. In favorable cases 14-Mev elastically-scattered neutrons were resolved from decay gamma rays. Nuclear temperatures obtained are in general agreement with photographic plate results.[2] Angular distributions were isotropic within statistical errors. A possible extension of the method to higher resolution, with an anticoincidence alpha counter to remove random background due to undesired neutrons, will be discussed.

[1] G. K. O'Neill, Phys. Rev. **92**, 853 (1953).
[2] E. R. Graves and L. Rosen, Phys. Rev. **89**, 343 (1953).

P3. Inelastic Scattering of 4.3-Mev Neutrons by Fe^{56}.* B. JENNINGS, J. B. WEDDELL, *Westinghouse Research Laboratories*, AND R. L. HELLENS, *Westinghouse Electric Corporation*.—The neutron spectrum from the scattering of 4.3-Mev neutrons by iron has been measured at 90° by the proton recoil photographic method. Two exposure geometries were employed; one, similar to that of Stelson and Preston,[1] used a 2×2 cm cylindrical scatterer. The second, with a different collimator and with a flat plate scatterer 6.4 mm thick, leads to a lower relative background, and is the basis of the following preliminary results. The neutron energies fall into groups corresponding to energy levels in Fe^{56} at 0.85, 2.1, 2.7, and perhaps 3.0 Mev. The total elastic cross section, using the Bartol[2] angular distribution measurement at 3.7 Mev, is estimated at 2.6±0.6 barns. The inelastic cross sections for the first three levels, assuming isotropic distribution, are estimated at 0.9±0.3, 0.4±0.2, and 0.2±0.1 barn, respectively. The errors stated include statistics, an estimate of track measurement uncertainties, and the incomplete determination of the background.

* Assisted by the joint program of U. S. Office of Naval Research and U. S. Atomic Energy Commission.
[1] P. H. Stelson and W. M. Preston, Phys. Rev. **86**, 132 (1952).
[2] W. D. Whitehead and S. C. Snowdon, Phys. Rev. **92**, 114 (1953).

P4. De-Excitation Gamma Rays from Inelastic Scattering of Neutrons.* GORDON L. GRIFFITH, *Westinghouse Research Laboratories*.—In conjunction with the direct measurements of the inelastic neutrons, observations have been made of the de-excitation gamma rays. The detector was a NaI(Tl) scintillation counter shielded from direct neutrons by a lead cone and surrounded by a ring of the scattering material being investigated. Pulse-height spectra for several elements have been obtained and the observed gamma rays correspond in general to previously known transitions. In those cases where both neutron and gamma-ray measurements have been made transition assignments are usually positive. Cross section determinations can not be made from the gamma ray measurements because of the multiple scattering in the large scatterers used.

* Jointly supported by U. S. Office of Naval Research and U. S. Atomic Energy Commission.

P5. Inelastic Scattering of Neutrons by Ba^{137} and Hg^{199}.* C. P. SWANN AND F. R. METZGER, *Bartol Research Foundation*.—The production by inelastic scattering of neutrons of the 527-kev isomeric level of Hg^{199} and of the 661-kev isomeric level of Ba^{137} have been studied. Neutrons were produced by bombarding a 50-kev lithium target with protons accelerated in the large Bartol Van de Graaff. The cross section for the production of the 13/2+ level of Hg^{199} increases sharply at 620±10-kev mean neutron energy indicating a level at about 90 kev above the metastable state. Below 620 kev the observed activity decreases with increasing neutron energy and is attributed mainly to fast neutron capture by Hg^{198}. At 620 kev the cross section corresponds to about one mb. Several other breaks indicate higher excited states in Hg^{199}. The 11/2-level of Ba^{137} has been excited with mean neutron energies as low as 670±10 kev indicating direct formation of the metastable state. The experimental cross section at 150 kev above the threshold is about 5 mb which is an order of magnitude smaller than the theoretical estimate based on the compound nucleus model.[1]

* Supported in part by the U. S. Atomic Energy Commission and in part by the joint program of the U. S. Office of Naval Research and the U. S. Atomic Energy Commission.
[1] W. Hauser and H. Feshbach, Phys. Rev. **87**, 366 (1952).

P6. Neutron Inelastic Scattering.* ROBERT M. KIEHN† AND CLARK GOODMAN, *M.I.T.*—Neutron inelastic scattering cross sections of Fe, Al, Cr, Ni, Pb, and Bi have been measured with ~20-kev resolution for neutron energies between 0 and 2.7 Mev. A NaI(Tl) gamma-ray spectrometer inside a hollow, conical scatterer measured the monoenergetic gamma rays emitted by the excited nucleus. The cross sections are in good agreement with predictions based on the Hauser-Feshbach theory. The energies of the first few excited states of the nuclei were found to be in good agreement with values obtained by other methods. New levels were found in Bi at 895±25 and 1560±35 kev. Levels at 200, 410, and 630 kev were also observed as a result of inelastic scattering within the detector.

* This work was supported by the joint program of the U. S. Office of Naval Research and the U. S. Atomic Energy Commission.
† Gulf Oil Corporation Fellow, now at Los Alamos Scientific Laboratory.

P7. Neutron Inelastic Scattering in Ta and I.* JANET B. GUERNSEY† AND CLARK GOODMAN, *M.I.T.*—Preliminary results indicate that the 136.5-kev first rotational state in Ta can be excited by 1.1-Mev neutrons. This observation may be interpreted by the Bohr-Mottelson theory[1] as an inelastic process without the formation of a compound nucleus. The detection of the 136-kev gammas, at neutron energies below 1 Mev, is made difficult by the presence of capture gamma radiation in NaI of about 150 kev. There is also evidence of gamma radiation from a low-lying state in I at about 46 kev presumably resulting from inelastic scattering. This level as well as the 200-, 410-, and 630-kev levels[2] has been assigned to I as a result of experiments using an I scattering cone.

* This work was supported by the joint program of the U. S. Office of Naval Research and the U. S. Atomic Energy Commission.
† On leave from Wellesley College.
[1] A. Bohr and B. R. Mottelson, Danske Videnskb. Selskab. Math.-fys. Medd. **27**, 158 (1953).
[2] See preceding abstract.

P8. Neutron-Capture Gamma-Ray Spectra.* MELVIN REIER, *Brookhaven National Laboratory*, AND MORRIS H. SHAMOS, *Physics Department, New York University*.—The low-energy component of the gamma-ray spectra, resulting from thermal neutron capture, was investigated by measuring the distribution of pulse heights incident upon a single NaI crystal and supplementing the information obtained this way by utilizing the Compton scattering technique.[1] Data in the region from about 100 kev to 2 Mev will be presented for a number of elements and will be discussed in terms of the proposed decay schemes. The following gamma rays have been observed:

Element	
Vanadium	2 unresolved lines at about 0.82, 0.64, 0.43.
Cobalt	1.82, 1.48, 0.82, 0.65, 0.289, 0.237.
Copper	0.280, 0.202.
Titanium	1.75, 2 unresolved lines between 1.53 and 1.58, 1.39, 2 unresolved lines between 1.06 and 1.10, 0.334.
Iron	2 unresolved lines between 1.55 and 1.68, 0.355.
Chromium	2.13, 1.07, 0.815, 0.740.
Gold	0.248.
Manganese	0.308, 0.266, 0.206, 0.098.
Iodine	0.255.

* Research performed under the auspices of the United States Atomic Energy Commission.
[1] Hofstadter and McIntyre, Phys. Rev. **78**, 619 (1950).

P9. The Gamma-Ray Spectrum from the Inelastic Scattering of Fast Neutrons in Iron.* D. L. LAFFERTY, L. A. RAYBURN, AND T. M. HAHN, *University of Kentucky.*—A complex spectrum of gamma rays has been obtained from the inelastic scattering of fast neutrons in iron. The source of fast neutrons was the $D-D$ reaction produced by the University of Kentucky Low-Voltage Accelerator. A ring-type geometry allowed the background to be subtracted from the total spectrum yielding the iron spectrum. An analysis of the pulse-height distribution from a NaI scintillation spectrometer reveals the presence of lines corresponding to energies of 2.66, 2.21, 2.10, 1.78, 1.70, 1.59, 1.40, 1.24, 1.098, 0.989, 0.892, 0.851, 0.675, and 0.462 Mev.

* Sponsored by the Office of Ordnance Research, U. S. Army.

P10. Gamma Rays Produced by the Inelastic Scattering of D−D Neutrons in Cu, Al, and Mg.* L. A. RAYBURN, D. L. LAFFERTY, AND T. M. HAHN, *University of Kentucky.*—Monoenergetic neutrons from the $H^2(d,n)$ He^3 reaction were used to bombard scatterers of Cu, Al, and Mg in the form of rings surrounding a gamma-ray spectrometer. The gamma rays resulting from inelastic scattering of the neutrons in the scatterers were detected by a spectrometer consisting of a NaI(Tl) crystal mounted on a DuMont 6292 photomultiplier tube. A single-channel differential pulse-height analyzer was used to analyze the pulses from the photomultiplier. No shielding was used between the neutron source and the NaI crystal. The gamma spectrum for each scatterer obtained by subtracting the background counting rate from the counting rate with scatterer in place will be presented.

* Sponsored by the Office of Ordnance Research, U. S. Army.

P11. Gamma Radiation from Interaction of 3.1-Mev Neutrons. V. E. SCHERRER, B. A. ALLISON, AND W. R. FAUST, *Naval Research Laboratory.*—Neutrons from the $D(d,n)$ He^3 reaction were allowed to fall on radiators made of aluminum, manganese, zirconium, arsenic, and bismuth. Various gamma-ray lines have been identified and correlated with established levels for the nuclei concerned. Estimates of the gamma-ray production cross section have been made for each radiator material.

P12. Differential Cross Section for Elastic Scattering of Neutrons from Nitrogen. C. H. JOHNSON AND J. L. FOWLER, *Oak Ridge National Laboratory.*—Neutrons produced by the $T(p,n)$ He^3 reaction were elastically scattered from a cylindrical sample of LiN_3 and detected by a propane recoil counter. The neutron energy spread resulting from the tritium gas target was 40 kev. The counter was shielded from the direct neutrons by paraffin slabs and was biased to have an approximate constant detecting efficiency for neutrons scattered at all angles from nitrogen. Background was found by scattering neutrons from a can containing the same amount of lithium as the original scatterer. Differential cross sections were measured over the region of $\cos\varphi$ (center-of-mass angle) from $+0.9$ to -0.7 at energies below 1.6 Mev (0.80, 1.28, 1.54 Mev). For $\cos\varphi<0.5$ the distributions are essentially isotropic in agreement with results found by observing nitrogen recoil energies in a counter.[1] At 1.28 and 1.54 the differential neutron measurements show an increased cross section for $\cos\varphi>0.5$. For this forward scattering, that is for low-energy recoils, the nitrogen recoil counter is not reliable. An interpretation of the resonance distributions will be discussed.

[1] Fowler, Johnson, and Risser, Phys. Rev. **91**, 441A (1953).

P13. Sphere Measurements of Neutron Inelastic Collision Cross Sections.* ROBERT C. ALLEN, *Los Alamos Scientific Laboratory.*—With a monoergic neutron source and an energy-discriminating neutron detector, the transmission of a sphere is a measure of the inelastic collision cross section. Neutrons up to 1.5 Mev are obtained from the $T(p,n)$ He^3 source with the 2.5-Mev Los Alamos electrostatic accelerator. The neutron detector is a small high-pressure hydrogen recoil proportional counter. The counter, which has a cylindrical counting volume one-half inch in length and one-half inch in diameter, can be placed inside a sphere of one and one-quarter inches diameter. With an argon hydrogen filling of ten atmospheres a good differential pulse-height distribution is obtained. Some results of the inelastic collision cross section as a function of energy and of the inelastic neutron spectrum will be discussed.

* Work done under the auspices of the U. S. Atomic Energy Commission.

FRIDAY AFTERNOON AT 2:00

Shoreham, West Ballroom

(ARTHUR ROBERTS presiding)

Meson Production

PA1. Photoproduction of π^+ Mesons near Threshold.* L. S. OSBORNE, Y. GOLDSCHMIDT-CLERMONT,† AND G. PARKER, *M.I.T.*—Nuclear emulsions were exposed in a gas hydrogen target[1] through which was passed the γ-ray beam from the 340-Mev electron synchrotron. The plates were scanned and rescanned for stopped π^+ mesons and identified by the $\pi-\mu$ decay. The scanning efficiency is estimated at better than 90 percent. Meson angles and ranges were converted to angles and energies in the center-of-mass system. In this system the angular distribution was roughly spherically symmetric. The average differential cross sections between 60° and 120° (center of mass) were

Meson energy in c of m system	$(d\sigma/d\tau)\times10^{30}$ cm²
2–5 Mev	2.4 ± 0.3
5–6.5 Mev	2.6 ± 0.8

* This work was supported in part by the joint program of the U. S. Office of Naval Research and U. S. Atomic Energy Commission.
† Now at Physikalisches Institut-ETH, Zurich, Switzerland.
[1] Goldschmidt-Clermont, Osborne, and Scott, Phys. Rev. **89**, 329 (1953).

PA2. Determination of Photo Cross Sections from Bremsstrahlung Activation Curves.* A. S. PENFOLD AND J. E. LEISS, *University of Illinois.*—When a photon-induced reaction is investigated by irradiating with bremsstrahlung, the number of reactions is related to the cross section for the reaction through the activation integral

$$a(E_0)=\int_0^{E_0} P(E_0,E)\sigma(E)dE.$$

The problem of obtaining staisfactory practical solutions of this equation has been investigated with the Illinois digital computer. The 0° thin target bremsstrahlung equation due to Schiff[1] was used as the kernel, $P(E_0,E)$. Two general types of solutions have been investigated; the first in terms of integral operators, and the second in terms of matrix operators. Explicit forms of some of these operators will be shown and the applicability of the solutions and their relation to previously published solutions will be discussed. The effect of

variations in $P(E_0,E)$ and of statistical errors in $\alpha(E_0)$ will be discussed.

* Supported in part by the U. S. Office of Naval Research, U. S. Atomic Energy Commission, and the National Science Foundation.
[1] L. I. Schiff, Phys. Rev. **83**, 252 (1951).

PA3. Photoproduction of π^+ Mesons from Hydrogen.* J. E. LEISS AND C. S. ROBINSON, *University of Illinois.*—The photoproduction of π^+ mesons from liquid hydrogen has been investigated using the activation curve method of the preceding abstract. Activation curves were obtained in a five-channel range telescope, by varying the betatron energy in 10-Mev steps from 140 to 300 Mev. Beyond 90° lab most counts represent π^+ mesons. Protons are dynamically excluded. The electron flux, including positrons from decay of mesons stopped in the target, is small and is subtracted on the basis of measurements below the meson counting threshold. These conclusions were confirmed with nuclear emulsions. Analysis of the activation curves yields values of the cross section for photon energies above the counting threshold in each channel. Comparison of different channels, after correction for multiple scattering, allows extrapolation of the results to zero absorber thickness. The cross section at 107°, 149°, and 165° (c.m.) has been determined from 200 to 300 Mev. The results at 107° and 149° agree essentially with other experiments. The cross section at 165° is about 15 percent lower than at 149°.

* Supported in part by the U. S. Office of Naval Research, U. S. Atomic Energy Commission, and National Science Foundation.

PA4. Photoproduction of π^+ Mesons from Hydrogen near Threshold.* C. S. ROBINSON AND J. E. LEISS, *University of Illinois.*—The activation curve method of the two preceding abstracts has been extended to energies near threshold by counting positrons from decay of mesons stopped in the target. A small x-ray beam passed through a target of sufficient size to stop most mesons created by photons up to 30 Mev above threshold. A telescope of 4-inch diameter scintillators was placed at 140°. At this angle pair electron background from hydrogen was small. A preliminary activation curve was obtained for hydrogen from a carbon-paraffin difference, by varying the betatron energy in 5-Mev steps from 130 to 220 Mev. This curve was analyzed to obtain the total cross section. Above 180-Mev photon energy an appreciable correction for mesons escaping from the target was necessary. This correction can be made accurately if an angular distribution of emitted mesons is assumed. These preliminary results are in agreement with a total cross section proportional to meson momentum up to 180 Mev, and with the results of Goldwasser and Bernardini.[1] An experiment with liquid hydrogen is being prepared.

* Supported in part by U. S. Office of Naval Research, U. S. Atomic Energy Commission, and National Science Foundation.
[1] Goldwasser and Bernardini, Bull. Am. Phys. Soc. **25**, No. 1, 18 (1954).

PA5. Yield of π^+-Mesons by 335-Mev Protons as a Function of Atomic Number. J. MERRITT AND D. HAMLIN, *University of California, Berkeley.*—The relative differential cross section $d^2\sigma/dEd\Omega$ was measured for the production of π^+ mesons at 0°±4° by 335-Mev protons on D, C, Cu, and Pb. The observed π^+ meson energies were 52, 88, and 147 Mev for C, Cu, and Pb. For D the meson spectrum from 40 to 140 Mev was observed. The mesons were counted electronically from signals generated in a trans-stilbene crystal telescope. Identification of the π^+ meson depended upon a fast coincidence in the first two crystals plus the $\pi-\mu$ decay in the third crystal of the telescope.[1] For C, Cu, and Pb the relative yield per nucleus can be explained by proton and meson attenuation within the nucleus. The attenuation of protons and mesons is consistent with mean free paths which have been measured in other experiments for protons and mesons in nuclear matter. This work was done under the auspices of the U. S. Atomic Energy Commission.

[1] Hamlin, Jakobson, Merritt, and Schulz, Phys. Rev. **84**, 857 (1) (1951).

PA6. π^+ Production in Hydrogen by 437-Mev Protons.* T. H. FIELDS, J. G. FOX, J. A. KANE, R A. STALLWOOD, AND R. B. SUTTON, *Carnegie Institute of Technology.*—The differential cross section for the process $p+p\rightarrow\pi^++d$ has been measured using a fast coincidence technique which detects both emergent particles. The target was liquid hydrogen, and the solid angle was defined by the meson counter. Absorption curves were taken on both the mesons and the deuterons. The contribution to the counting rate from the reaction $p+p\rightarrow\pi^++p+n$ is believed negligible since the deuteron range curve indicates no component corresponding to slow protons, and since the counting rate does not depend on the solid angle of the deuteron counter as long as the meson counter defines the solid angle. Measurements have been made at c.m. angles of 30°, 50°, and 90° yielding cross sections of 0.192, 0.121, and 0.039 mb/sterad, respectively, with statistical errors of about 7 percent. These points can be well fitted by an angular distribution of $(0.20\pm0.02+\cos^2\theta)$ and yield a total cross section of 1.35±0.13 mb. These values are in good agreement with those on the inverse reaction[1] for π^+ spin = 0. Work on the reaction $p+p\rightarrow\pi^++p+n$ is in progress.

* Work supported in part by U. S. Atomic Energy Commission.
[1] Durbin, Loar, and Steinberger, Phys. Rev. **84**, 581 (1951).

PA7. Pion Production by 440-Mev Protons Incident upon Hydrogen and Carbon.* ARTHUR H. ROSENFELD,† *University of Chicago.*—The energy spectrum of pions produced in $P-P$ collisions has been measured at three angles using 440-Mev protons. About half the time bound deuterons are formed. $d\sigma/d\Omega\propto(0.15\pm0.05+\cos^2\theta)$; $\sigma=(4.26\pm0.9)$ mb. If charge independence applies to pion production in nucleon-nucleon collisions, then there are only three independent cross sections whose excitation functions have been given by Watson and Brueckner.[1] All available data are compiled and agree well with the theory. One of the three cross sections is small; the other two are normalized separately to fit the data. We find $\sigma(P+P\rightarrow n^++D)=1.0\text{ mb}\times\eta^3$, where η is the c.m. pion momentum in units of μc. The experimental ratio $\sigma(P+P\rightarrow n^++N+P)/\sigma(P+P\rightarrow n^++D)$ seems slightly larger than predicted by Watson. We find $\sigma(P+P\rightarrow n^0)=0.22\text{ mb}\times\eta^6$. The energy spectrum of n^+ and n^- produced in a carbon target at 90° lab. has also been measured. We find $(d\sigma/d\Omega)_{90^\circ}=(0.83\pm0.11)$ mb/sterad, and a n^+/n^- ratio of 7.2±1.5.

* Work supported in part by the U. S. Office of Naval Research.
† National Science Foundation Fellow.
[1] K. M. Watson, Phys. Rev. **88**, 1163 (1952).

PA8. The Production of Positive and Negative Pions in Beryllium by 1.0 and 2.3-Bev Protons.* S. J. LINDENBAUM AND LUKE C. L. YUAN, *Brookhaven National Laboratory.*—The momentum spectrum and relative cross section for the production of negative and positive pions in beryllium by 1.0-Bev protons was observed at a 32° laboratory angle in a manner similar to that reported[1] for 2.3-Bev protons. Assuming that beryllium is a light enough nucleus so that one is essentially observing the elementary proton-nucleon meson production, the pion spectra in the c.m. system show a peak at ~100 Mev for both 1.0 and 2.3-Bev incident protons. The results disagree with the Fermi statistical theory predictions.[2] Although the inclusion of the apparent pion-nucelon resonance interaction in the final state statistical weights would possibly explain the 2.3-Bev results, the similarity of 1.0-Bev and 2.3-Bev spectra suggests that this resonance state may play a

fundamental role in these processes. R. Serber has suggested that a shake-off from the meson cloud could explain the results.

* Work performed under the auspices of the U. S. Atomic Energy Commission.
[1] Luke C. L. Yuan and S. J. Lindenbaum, Phys. Rev. (to be published).
[2] Christian and Yang, B. N. L. Report, December, 1953.

PA9. Neutral Pion-Deuteron Production in High-Energy n-p Collisions.* ROBERT A. SCHLUTER, *University of Chicago.*—The reaction $n+p\rightarrow D+\pi^0$ has been observed in a high-pressure hydrogen diffusion cloud chamber. Deuterons are identified by a technique of ionization measurement in conjunction with momentum measured in the 10 500 gauss magnetic field. Several cases of internally converted π^0 gamma-rays confirm the method of identification. The flux and spectrum of the 400 ± 25 Mev neutron beam of the Chicago synchrocyclotron are measured by proton recoils observed simultaneously. The ratio of deuterons to protons of laboratory angle $\leq 30°$ representing neutrons of >350 Mev, is 0.047 ± 0.015. Using published data on n-p scattering, the total cross section is 0.6 ± 0.2 mb, agreeing, within the accuracy of the measurements, with the prediction of charge independence that the ratio of this reaction to $p+p\rightarrow D+\pi^+$ should be $\frac{1}{2}$. The angular distribution of the pions will be presented.

* Supported by the U. S. Office of Naval Research and the U. S. Atomic Energy Commission.

PA10. Negative Pion Production in n-p Collisions.* S. C. WRIGHT AND R. A. SCHLUTER, *University of Chicago.*—We have studied the production of π^- mesons in n-p collisions by bombarding a high-pressure hydrogen diffusion cloud chamber with 400 ± 25 Mev neutrons from the Chicago synchrocyclotron. With the same incident beam the reaction $n+p\rightarrow D+\pi^0$ (see previous abstract) is favored by a factor $\left(3.8^{+1.9}_{-1.4}\right)$ compared to $n+p\rightarrow\pi^-+2p$. In the center-of-mass coordinate system there appears to be no strong correlation between the two protons. Details of the energy and angular distributions of the product particles will be presented.

* Supported by the U. S. Office of Naval Research and the U. S. Atomic Energy Commission.

FRIDAY AFTERNOON AT 2:00

Sheraton Park, Burgundy Room

(C. C. LAURITSEN presiding)

Reactions of Transmutation. I

Q1. $(p,2n)$, $(p,2p)$, (p,t), $(p,\mathrm{He_3})$, and (p,f) Cross Sections and Excitation Functions. B. L. COHEN, G. H. MCCORMICK, T. H. HANDLEY, AND E. NEWMAN, *Oak Ridge National Laboratory.*—Cross sections and excitation functions for several $(p,2n)$, $(p,2p)$, (p,t), $(p, \mathrm{He_3})$, and (p,f) reactions have been measured using 22-Mev protons from the internal circulating beam of the ORNL 86-inch cyclotron. $(p,2n)$ excitation functions in medium weight elements show an energy dependence corresponding to a nuclear temperature of about 2 Mev, but the absolute cross sections are smaller than can be understood from existing theories by large factors. The ratio of $(p,2p)$ to (p,pn) cross sections is approximately as predicted by statistical theory; this indicates that Coulomb barriers are quite effective in suppressing the emission of low-energy protons, and that the phenomenon of excessive charged particle emission is not strongly evident in "second particle" emission from nuclear reactions. The difference in level densities by a factor of four between even-even and odd-odd nuclei is quite evident from this data. The cross sections for the (p,t) reaction in iron and the $(p, \mathrm{He_3})$ reaction in zinc are about equal to, and about ten times less than, respectively, the predictions of the statistical theory. The (p,f) cross sections in U^{235} and U^{235} are about equal to the total reaction cross section at all energies up to 22 Mev, but in Th^{232}, it is only about 60 percent as large.

Q2. Neutron Thresholds from (d,n) and (p,n) Reactions.* C. F. COOK, T. W. BONNER, AND J. B. MARION, *The Rice Institute.*—The two counter technique for detecting neutron thresholds has been used to study (d,n) and (p,n) reactions. A slow neutron counter and a conventional long counter are arranged to subtend the same solid angle with the neutron source. The ratio of counts in the slow counter to counts in the long counter exhibits a sharp rise at the thresholds and then falls off almost exponentially with increasing neutron energy. Resonances in the compound nucleus are exhibited by both counters, but the ratio remains unchanged. This method has been applied to $C^{13}(d,n)N^{14}$. A broad level at 3.28-Mev deuteron energy has been observed. This level corresponds to an excited state in N^{14} of 8.16 Mev. The observed half-width was about 300 kev. Results from bombardment of B^{10} and B^{11} will also be presented.

* Supported by the U. S. Atomic Energy Commission.

Q3. Angular Distribution of Deuterons from (p,d) Reactions in Light Nuclei.* J. B. REYNOLDS AND K. G. STANDING,† *Princeton University.*—Deuterons resulting from the bombardment of various elements with 18-Mev protons were observed, using a method developed by one of us.[1] The angular distribution of deuterons from the reaction $X(p,d)Y$ can be fitted with a theoretical (Butler) curve calculated for the inverse reaction $Y(d,p)X$. Angular distributions were observed for reactions leading to the following final nuclei, Y: Li^6, $r_0=5.0$; Li^{6*}(2.19 Mev); Be^8, $r_0=3.0$; B^9, $r_0=4.5$; B^{9*}(2.4 Mev), $r_0=4.7$; B^{10}; F^{18}, $r_0=5.0$; Al^{26}. Values of Butler's r_0 (in units of 10^{-13} cm) are given as obtained by comparing theory and experiment. In all cases, except F^{18} and Al^{26}, the angular momentum ln carried away from the target nucleus by the pickup neutron was unity. For F^{18} and Al^{26}, ln = 0 and 2, respectively. From these results it can be concluded that X and Y have opposite parity for all of the above reactions except the last two for which X and Y have the same parity.

* This work was supported by the U. S. Atomic Energy Commission and The Higgins Scientific Trust Fund.
† Now at the University of Manitoba, Winnipeg, Canada.
[1] K. G. Standing, Phys. Rev. (to be published).

Q4. Comparison of the Reactions $H^1(H^2\pi^+)H^3$ and $H^1(H^2\pi^0)He^3$ as a Test of Charge Independence. KENNETH C. BANDTEL, WILSON J. FRANK, RICHARD MADEY, AND BURTON J. MOYER, *University of California, Berkeley.*—A comparison study of these reactions is of interest because of the conclusions that can be drawn with regard to the conservation of isotopic spin, or in other words, the principle of charge

independence of nuclear forces. Conservation of isotopic spin predicts that the value of the differential cross section for the H^3 reaction will be twice that for the He^3 reaction. A liquid deuterium target was bombarded by 340-Mev protons from the Berkeley 184-in. synchrocyclotron. The reaction $H^1(H^2\pi^+)H^3$ has been studied previously[1] by utilizing the difference in time of flight between the π^+ and the H^3. In addition, E and dE/dx for the H^3 and He^3 particle is measured. These pulses are displayed in succession on the sweep of a Tektronix 517 scope. They are photographed and the pulse heights are then read off the film. Both final products are detected in case of the H^3 reaction. Only the He^3 particle is detected because of the uncertainty in the efficiency of a γ-ray counter. A comparison of the two cross sections can be obtained under the same conditions, thus eliminating many systematic errors. Preliminary results are not inconsistent with the predicted ratio. This work was done under the auspices of the U. S. Atomic Energy Commission.

[1] Frank, Bandtel, Madey, and Moyer, Phys. Rev. (to be published).

Q5. Fast Neutron Scintillation Spectra of $Li^6(n,\alpha)H^3$ in LiI(Eu). J. H. Neiler, F. Muckenthaler, and James Schenck, *Oak Ridge National Laboratory.*—Pulse-height spectra produced by the $Li^6(n,\alpha)H^3$ reaction in LiI(Eu) crystals of several activator concentrations have been obtained for neutrons of 2.3, 3.6, 5.0, and 16.7 Mev. Although the spectra exhibit good resolution for both thermal and fast neutrons, the fast neutron reaction produces a band rather than a line. Such a shape is to be expected if the pulse height *versus* energy response of the crystal to alpha particles is nonlinear for the alpha energies produced in this reaction. The data indicate that the pulse height produced by tritons is greater than that of electrons of the same energy. A possible explanation of this effect, which depends upon the self-absorption of the emitted light of LiI(Eu) crystals, will be presented.

Q6. Reaction Particles from 14.5-Mev Deuteron Bombardment of Li^7 and Li^6.* S. H. Levine, R. S. Bender, J. N. McGruer, and W. F. Vogelsang, *University of Pittsburgh.*—Observations have been made of the angular distributions of charged particles resulting from the deuteron bombardment of natural lithium. 14.5-Mev deuterons were incident upon a thin Li target and outgoing particles were analyzed with a magnetic spectrometer. The detector was a CsI crystal and the particles were identified by pulse-height analysis and by their ranges in foils. The following reactions were observed:

Reaction	Levels (Mev)
$Li^7(d,t)Li^6$	g.s., 2.187
$Li^7(d,d)Li^7$	g.s., 0.478, 4.61
$Li^7(d,p)Li^8$	g.s., 1.0, 2.28
$Li^7(d,He^3)He^6$	g.s., 1.71
$Li^7(d,d)He^5$	g.s.
$Li^6(d,He^3)He^5$	g.s.
$Li^6(d,p)Li^7$	g.s., 0.478, 6.56

Present data when compared with Butler curves favor $l=1$ transfer for the two triton groups and the He^3 group corresponding to the ground state of He^6.

* Work done at the Sarah Mellon Scaife Radiation Laboratory and assisted by the Joint Program of the U. S. Office of Naval Research and the U. S. Atomic Energy Commission.

Q7. The $Li^7(d,p)Li^8$ Yield Curve.* Stanley Bashkin, *State University of Iowa.*—The S.U.I. mevatron was used to measure the cross section for the $Li^7(d,p)Li^8$ reaction from $E_d=700$ kev to 3200 kev. Previously reported resonances[1] at 750 kev and 1000 kev appeared at 812 kev and 1040 kev, respectively; no evidence of the reported resonance at 1400 kev was found. The yield rises rapidly from 1200 kev to 1500 kev, less rapidly to 1900 kev, and is flat thereafter to 3200 kev. The decay betas from $Li^8(t_{\frac{1}{2}}=0.8$ sec) were detected with a thin NaI(Tl) crystal coupled to a 5819 photomultiplier. A strongly energy-dependent background of neutron capture γ rays increased from one tenth of the beta counts at 700 kev to seven times the beta counts at 3200 kev. The betas passed through an electromagnet before reaching the detector. When the field was off, background and betas were counted. When the field was on, the betas were deflected to one side and only the undisturbed background was recorded. The difference in readings gave the number of betas.

* Supported in part by the U. S. Atomic Energy Commission.
[1] Baggett and Bame, Phys. Rev. **85**, 434 (1952).

Q8. The $Li^7(He^3,p)Be^9$ Reaction. W. E. Kunz, C. D. Moak, and W. M. Good, *Oak Ridge National Laboratory.*—The following competitive processes were investigated in the bombardment of a $Li_2{}^7SO_4$ target with He^3:

$$He^3+Li^7\rightarrow B^{10}\rightarrow Be^9+H^1+11.19 \text{ Mev} \quad (1)$$

$$Be^8+H^2+11.75 \quad (2)$$

$$Li^6+He^4+13.32 \quad (3)$$

$$2He^4+H^1+n+9.61. \quad (4)$$

A NaI crystal spectrometer was used to study these reactions. Spectrometer calibration was obtained from the 14.7-Mev protons produced by $He^3(d,p)He^4$. Absorbers were used to distinguish different particles. The spectrum consisted of a continuum of protons and alphas from (4) on which was superposed 4 sharp particle groups and a single broad particle group. The most consistent interpretation of the particle groups is that each group consists of protons. Only a trace of reaction (2) was evident and reaction (3) was easily discerned. If indeed all the proton groups come from (1) then Be^9 would have the following states: ground, 1.87, 2.58, 3.24, and a broad state as 4.89.

Q9. A Proton Recoil Telescope for Observing Neutron Spectra. Carroll C. Trail* and C. H. Johnson, *Oak Ridge National Laboratory.*—A proton recoil telescope has been constructed to measure the neutron spectrum from the $Li^7(d,n)Be^8$ reaction. The neutrons impinge upon a polyethylene radiator and protons recoiling in the forward direction give rise to proportional counter pulses and terminate in a NaI scintillation counter. The photomultiplier impulses are analyzed by a multichannel pulse sorter which is gated by coincidences between the scintillation counter pulses and the proportional counter pulses. Polyethylene radiators of different thicknesses are mounted upon a wheel inside the counter. Radiator thicknesses were selected so that the energy spread of the recoil protons could be limited to 5 percent of the incident neutron energies for energies greater than 3 Mev. The efficiency of the counter for these radiators is 5×10^{-6}. The neutron spectrum of the $Li^7(d,n)Be^8$ reaction has been studied at 0°. Preliminary results with 10 percent statistics indicate only one excited state of Be^8 below 9 Mev.

* Graduate student at Texas A. and M. College working under an Oak Ridge Institute of Nuclear Studies fellowship.

Q10. Resonance Near the $Li^7(p,n)$ Threshold.* H. W. Newson and J. H. Gibbons, *Duke University.*—The total neutron yield has been measured as a function of proton energy from threshold to about 2.4 Mev. The resulting curve was normalized to that of Taschek and Hemmendinger.[1] The two curves agree well except near threshold where there is a rapid rise for a few kilovolts until the yield becomes practically constant at a proton energy of 1.900 Mev. Dividing the cross section by the neutron velocity in the center-of-mass system, it is apparent that there is a resonance near threshold; the curve has a maximum at 1.888 Mev which is evidently due to

target thickness and proton energy spread. Correcting for these effects it is evident there is no true maximum but the curve appears slightly flatter near threshold than at higher energies. The peak found by Bashkin and Richards[2] at 1.87 Mev is probably due to the same resonance; a resonance in this general region has been predicted by Breit and Bloch.[3]

* Work supported by U. S. Atomic Energy Commission.
[1] R. Taschek and A. Hemmendinger, Phys. Rev. **74**, 373 (1948).
[2] S. Bashkin and H. T. Richards, Phys. Rev. **84**, 1129 (1951).
[3] G. Breit and I. Bloch, Phys. Rev. **74**, 397 (1948).

Q11. The Be^9+He^3 Reactions. C. D. Moak, W. M. Good, and W. E. Kunz, *Oak Ridge National Laboratory.*—The charged particle spectrum for the case of He^3 on Be^9 has been measured with a NaI charged particle spectrometer. The following reactions were observed:

$$Be^9+He^3 \rightarrow B^{11}+H^1+10.32 \text{ Mev} \quad (1)$$

$$\rightarrow Be^8+He^4+18.90 \text{ Mev}. \quad (2)$$

In addition, neutron measurements indicate that the following reaction takes place:

$$Be^9+He^3 \rightarrow C^{11}+n^1+7.56 \text{ Mev}. \quad (3)$$

In reaction (1) the proton spectrum shows the excited states already reported in the case of $B^{10}(d,p)B^{11}$.[1] The presence of α particles in the spectrum has been verified through the use of Al absorbers placed between the target and the NaI crystals. The charged particle spectra and thin target yield measurements will be presented.

[1] Van Patter, Buechner, and Sperduto, Phys. Rev. **82**, 248 (1951).

Q12. Capture Gamma Rays from 315-Kev Proton Bombardment of Be^9.* R. R. Carlson and E. B. Nelson, *State University of Iowa.*—A three crystal scintillation spectrometer detected 6.7 ± 0.15, 6.0 ± 0.15, 5.1 ± 0.1, and 4.7 ± 0.15 Mev gamma rays with relative intensities (±25 percent) of 0.15, 0.40, 1.00, and 0.45, respectively. These energies correspond to transitions in B^{10} from the capture state at 6.87 ± 0.04 Mev to the ground state and low-lying levels at 0.72, 1.74, and 2.15 Mev.[1] The observed relative intensities and the known spins and parities[1] of the ground state and 1.74-Mev excited state of B^{10} imply spin one for the capture state. A thick target yield of $(1.2\pm0.3)\times10^{-10}-5.1$ Mev gammas per proton was found by comparison with the fluorine gamma-ray yield. Combined with the thin target excitation function,[2] this gives the cross section at resonance (336 kev) for the emission of 5.1-Mev gamma radiation as $(1.2\pm0.4)\times10^{-29}$ cm^2. A single-crystal spectrometer, limited to 2 Mev, detected 0.72 ± 0.02, 1.03 ± 0.03, and 1.43 ± 0.03 Mev gamma rays corresponding to transitions between low-lying levels in B^{10}.

* Supported in part by the U. S. Atomic Energy Commission.
[1] F. Ajzenberg and T. Lauritsen, Revs. Modern Phys. **24**, 321 (1952).
[2] S. E. Hunt, Phys. Rev. **87**, 902 (1952).

Q13. Gamma-Gamma Correlation in $Be^9(d,n)B^{10*}(\gamma)B^{10}$. S. M. Shafroth* and S. S. Hanna, *The Johns Hopkins University.*†—The 2.86- and 0.72-Mev gamma rays from the $Be^9(d,n)B^{10*}(\gamma)B^{10}$ reaction were detected in coincidence. Two sodium iodide scintillation counters were employed, followed by pulse-height analysis and coincidence detection. Thick beryllium targets were used with a bombarding energy of 0.66 Mev. If θ_1 and θ_2 denote the angles of the 2.86- and 0.72-Mev gamma rays, respectively, measured with respect to the beam, and ϕ the dihedral angle between them, the correlation function may be expressed by $W(\theta_1,\theta_2,\phi)$. The following measurements were obtained:

	A_2
$W(\pi/2,\theta_2,\pi)$	0.05 ± 0.03
$W(\theta_1,\pi/2,\pi)$	0.05 ± 0.03
$W(\theta_1,2\pi/3,\pi)$	0.04 ± 0.05
$W(\pi/2,\theta_2,\pi/2)$	-0.01 ± 0.05
$W(\theta_1,\pi/2,\pi/2)$	-0.03 ± 0.05

A_2 is the coefficient in the expression $1+A_2\cos^2\theta$, where θ is either θ_1 or θ_2 (in the third correlation $\theta=\theta_1+\pi/6$). Spin assignments to the states in B^{10} will be discussed on the basis of these results.

* Now at Northwestern University.
† Supported by the U. S. Atomic Energy Commission.

Q14. Magnetic Analysis Indicating Charge Symmetry in the Reaction $Be^9(p,\alpha)Li^6$. R. Malm and D. R. Inglis, *Argonne National Laboratory.*—Alphas from $Be^9(p,\alpha)Li^6$ corresponding to the ground state and first excited state of Li^6 show no sign of resonance as the proton energy passes through 2.565 Mev where the transition to the second excited state, the 3.58-Mev state having $T=1$, shows a known gamma resonance. This is consistent with charge symmetry or with conservation of isobaric spin T if the resonant state is assumed to have $T=1$. The observations were made with a 16-inch radius, two-dimensional focusing, magnetic spectrometer the construction and performance of which will be described.

Q15. The Angular Distribution of 12-Mev and 16-Mev Gamma Rays from Proton Bombardment of Boron.* H. H. Givin, G. K. Farney, T. M. Hahn, and B. D. Kern, *University of Kentucky.*—The angular distributions of 12- and 16-Mev gamma rays from the reaction $B^{11}(p,\gamma)C^{12}$ have been measured as a function of proton bombarding energy up to 2 Mev. Thin targets were used and corrections were made for the absorption of gamma rays by the tantalum target backing. At each proton energy, the gamma-ray spectrum was obtained at each of seven angles. Angular distributions of the 12- and 16-Mev components were determined from appropriate integrations of the spectrum. Expressing the angular distributions in the form $1+A\cos\theta+B\cos^2\theta$, tentative values of the coefficients at representative energies are shown:

E_p (kev)	A_{16}	B_{16}	A_{12}	B_{12}
700	−0.05	0.18	0.03	−0.13
1000	−0.03	0.14	0.11	0.06
1200	0.02	0.15	0.16	0.09
1400	0.05	0.20	0.17	0.08
1600	0.00	0.24	0.18	0.13

* Sponsored by the Office of Ordnance Research, U. S. Army.

Q16. Neutrons from the Proton Bombardment of B^{10}.† F. Ajzenberg, *Boston University*, and W. Franzen* and J. G. Likely, *Princeton University.*—A B^{10} target, 200-kev thick, has been bombarded with 17.3-Mev protons from the Princeton cyclotron. The resultant neutrons have been studied by means of Ilford C-2 emulsions, 200 and 400 microns thick, mounted approximately 4.5 inches from the target and at five angles to the incident beam. Preliminary measurements at 30, 120, and 150 degrees (2200 tracks) indicate a ground-state Q value of -4.35 ± 0.2 Mev, giving a mass defect for C^{10} of 10.6 Mev, in fairly good agreement with beta-decay results.[1] The data also indicate an excited state of C^{10} at 3.4 Mev and unresolved levels at higher excitation energies.

† This work has been supported in part by the U. S. Air Force through the Office of Scientific Research and in part by the joint program of the U. S. Office of Naval Research and the U. S. Atomic Energy Commission.
* Now at the University of Rochester.
[1] R. Sherr and J. B. Gerhart, Phys. Rev. **91**, 909 (1953).

FRIDAY AFTERNOON AT 2:00

Sheraton Park, Caribar Room

(G. E. UHLENBECK presiding)

Theoretical Physics, IV: Statistical Mechanics

Invited Paper

QA1. The Excluded-Volume Problem. ROBERT J. RUBIN, *Applied Physics Laboratory, Johns Hopkins University.* (30 min.)

Contributed Papers

QA2. Equations of Motion of Coupled Ordered and Dissipative Systems.* J. L. JACKSON, *Applied Physics Laboratory, The Johns Hopkins University.*—J. Weber has investigated[1] in detail the exchange of energy between an ordered system and a dissipative system. The ordered system considered was an ideal electrical oscillator (condenser and inductance) and the dissipative system a generalized circuit element of the type described by Callen and Welton.[2] It has been found possible to derive the equations of motion (in this case the Kirchoff laws) for such coupled systems from the Hamiltonian. Two Kirchoff equations are nonstatistical in nature and are obtained directly as two of the Hamilton equations. The third Kirchoff equation, the one involving the voltage drop across the dissipative system, is a statistical one and is valid only within the limits of first-order perturbation theory. The coefficients in the differential equation for the current through the dissipative system involve exactly the impedances calculated previously by this author.[3]

* This work was supported by the Bureau of Ordnance, Department of the Navy.
[1] J. Weber, Phys. Rev. **90**, 977 (1953).
[2] H. B. Callen and T. A. Welton, Phys. Rev. **83**, 34 (1951).
[3] J. L. Jackson, Phys. Rev. **87**, 471 (1952).

QA3. Solution of the Transport Equation for the Case of Slab Geometry.* J. LEHNER AND G. M. WING, *Los Alamos Scientific Laboratory* (introduced by F. C. Hoyt).—We consider the one velocity flow of neutrons in a uniform infinite slab of thickness $2a$ immersed in a vacuum. Assuming isotropic scattering, the linearized Boltzmann equation may be written

$$-\mu\frac{\partial N}{\partial x}(x,\mu,t)-\sigma N+\frac{c}{2}\int_{-1}^{1}N(x,\mu',t)d\mu'=\frac{1}{v}\frac{\partial N}{\partial t}$$

with $N(\pm a,\mu,t)=0$, $\mu\lesseqgtr 0$. It has long been customary to assume that there exists a complete infinite set of eigenfunctions $N_i(x,\mu,t)=e^{\alpha_i t}n_i(x,\mu)$ in terms of which the initial value problem may be solved. It is proved that this is false, and that the set of eigenfunctions is always finite but nonempty. A solution to the initial value problem is obtained as a sum over this finite set plus an integral. The behavior of this integral for large time is determined.

* Work done under the auspices of the U. S. Atomic Energy Commission.

QA4. On the Principle of Minimum Entropy Production. MARTIN J. KLEIN AND PAUL H. E. MEIJER, *Case Institute of Technology.**—The characterization of the steady state in irreversible processes as the state of minimum entropy production is one of the most interesting aspects of irreversible thermodynamics. We have attempted to derive this property of the steady state by applying the methods of statistical mechanics. The particular model considered was the Knudsen gas: two identical vessels, containing the same ideal gas, maintained at temperatures T and $T+\delta T$, respectively, are connected by a small opening. Using the stochastic equations for the time rates of change of the occupation numbers in the containers, and generalizing a method developed by Thomsen,[1] we have been able to prove that the steady state corresponds to a minimum value of dS/dt. It was essential to include the entropy contributions of the two heat baths (T and $T+\delta T$). The results can be put in a form parallel to that given by Casimir[2] and give some insight into the heat of transport.

* Supported by a grant from the National Science Foundation
[1] J. S. Thomsen, Phys. Rev. **91**, 1263 (1953).
[2] H. B. G. Casimir, Revs. Modern Phys. **17**, 343 (1945).

QA5. Dynamical Behavior of Collective Coordinates in the New Approach to the Many-Body Problem. GEORGE J. YEVICK, *Stevens Institute of Technology,* AND JEROME K. PERCUS, *Columbia University.*—To eliminate the nonlinearity in the dynamical equations of motion for many interacting particles, we[1] have utilized collective coordinates to develop an equivalent but linear theory. As further verification of the equivalence between the oscillator Lagrangian and the true Lagrangian, we have explicitly calculated the equations of motion for the x_i using the collective Lagrangian. We can then show that these equations of motion reduce to the correct set by precisely the same choice of fictitious oscillator masses and frequencies required for conformability between the two Lagrangians. In so doing, we were driven to use many collective coordinates q_k with wavelengths much smaller than the mean interparticle spacing, in order to adequately represent the interparticle potential. Clearly these q_k's cannot represent organized behavior and must be the reservoir for the chaotic thermal energy of the system. The coupling between the low and high q_k's is due principally to the velocity dependent potentials which are treated in the theory as perturabations. The influence of these coupling terms on the degradation of energy from the low to the high k is now being considered as the mechanism for irreversibility.

[1] See Bull. Am. Phys. Soc. 29, No. 1, Abstracts U4 and U5 (1954).

QA6. Domain of Action of Collective Coordinates in the New Approach to the Many-Body Problem. JEROME K. PERCUS, *Columbia University,* AND GEORGE J. YEVICK, *Stevens Institute of Technology.*—In order to evaluate the classical partition function using the new collective coordinate approach to the many body problem, and even more important, in order to set up the quantum mechanical problem for the collective coordinates, it is paramount to determine the domain of action of the collective coordinates. As a possible approach to this difficult problem, we have been making a comparison between the classical partition functions in x space and q space. We expand $V(x_i-x_j)$ by means of its Fourier coefficients V_k. With a multiple Maclaurin expansion of the two partition functions using variables $(1/T)$ and V_k (T denotes the absolute temperature), an equating of coefficients allows us to compute successive mixed moments of the q_k's. Making the assumption of separability of q space into a product of two-dimensional spaces, we can evaluate these moments, and thus the q-space distribution, by means of a

generating function. This results in a new expression for the classical partition function which has been obtained by neglecting certain combinations of terms because of the properties of the V_k's and the fact that we have only a finite number of k's. This partition function is now being analyzed.

QA7. Statistical Aspects of the Second Law of Thermodynamics. C. D. GREEN AND D. TER HAAR,* *St. Andrews University, Scotland.*—Extending previous investigations[1] to more physical models mean life times and mean times of recurrence for nonequilibrium situations are calculated. The models investigated include the Ehrenfests' two-dimensional wind-wood model,[2] a one-dimensional model with a velocity distribution, models with isotropic scattering and a model with a one-dimensional Maxwell distribution.

* On leave of absence at Purdue University.
[1] D. ter Haar and C. D. Green, Proc. Phys. Soc. (London) **A66**, 153 (1953).
[2] P. and T. Ehrenfest, Anz. Math. Wiss. **4**, part 32 (1911).

QA8. Simplified Model of a Stationary Nonequilibrium Process.* HARRY L. FRISCH AND JOEL L. LEBOWITZ, *Syracuse University.*—A Gibbs ensemble will describe a stationary process if the Liouville equation of the system is modified by additional terms describing the stochastic interaction with surroundings, provided the surroundings are at different temperatures. In that case there will be a flux of energy through the system whose ensemble average does not vanish. Probably the simplest model of such a process is a single one-dimensional particle traveling back and forth between two large pistons having different mean energies of vibration. Because even this model leads to a rather involved integral equation, we have simplified it further by assuming that some of the reflections from the pistons are as from rigid walls, with the remainder (a fixed percentage of all reflections) leading to a redistribution of velocity independent of the incident velocity. This redistribution may be thought of as a surface adsorption with subsequent release. This new model is mathematically so simple that the solutions of the integro-differential equation can be obtained in full by relatively elementary methods. The results will be presented.

* This research was supported by Office of Scientific Research.

QA9. The Quantum-Mechanical Molecular Distribution Functions in a One-Dimensional Fluid Composed of Hard Spheres.* ROBERT J. RUBIN, *Applied Physics Laboratory, The Johns Hopkins University.*—The Schrödinger equation for N hard sphere molecules of mass m and diameter b in a one-dimensional box of length $a>Nb$ is identical with that for one particle of mass m in a special region of an N-dimensional cube. Consider a set of N orthogonal axes y_i and the N-dimensional cube with one corner at the origin, whose edges are in the direction of the coordinate axes and of length $a-Nb$. The polyhedron-like region is that portion of the cube such that $0\leqslant y_1\leqslant\cdots\leqslant y_i\leqslant\cdots\leqslant y_N\leqslant a-Nb$ and $y_i=x_i-(i-\frac{1}{2})b$, where x_i is the coordinate of the ith molecule. The eigenvalue and eigenfunction of a particular stationary state are

$$E_K=\sum_{K_i\neq K_j}^{N}\frac{K_i^2\hbar^2}{8m(a-Nb)^2},\quad \psi_K=D\left[\left(\frac{2}{a-Nb}\right)^{\frac{1}{2}}\sin\frac{K_i\pi y_j}{a-Nb}\right]$$

where $D[\ ]$ is an $N\times N$ determinant. The probability per unit length that any molecule will be at x is

$$\rho^{(1)}(x)=\langle\bar{\psi}_K\sum_{n=1}^{N}\delta(x_n-x)\psi_K\rangle.$$

* This work was supported by the Bureau of Ordnance, Department of the Navy, under Contract NOrd-7386.

QA10. Statistical Mechanics of Temperature-Dependent Energy Levels. P. T. LANDSBERG, *University of Pennsylvania, and University of Aberdeen, Scotland.**—The method of the Gibbs ensemble does not apply to systems whose energy levels E_i depend on the temperature. As a generalization, suppose that $\exp(-E_i/kT)$ be replaced by $\exp(-f_i)$ when the basic relations for the ensemble are set up. f_i is some function of E_i and T. The total energy, entropy (S), free energy (F) per system, as averaged over the ensemble, are now given by generalizations of the usual equations. The restriction that this ensemble shall lead to the usual laws of thermodynamics must still be imposed. In particular, the condition $(\partial F/\partial T)_{V,N}+S=0$ yields a complicated condition which involves the E's, the f's, and their temperature derivatives. If $f_i=E_i/kT$, one finds that the Gibbs ensemble is suitable for physical systems only if $(\partial E_i/\partial T)_{V,N}$, as averaged over the ensemble, is known to vanish. If $f_i=\int[E_i(T)/kT^2]dT$, as proposed by Rushbrooke,[1] the system must satisfy another more complicated relation. It would appear, therefore, that a more far-reaching generalization than that given by Rushbrooke, or possibly even that given by the class of ensembles which we have discussed here, will be required to deal adequately with system whose energy levels may be arbitrary functions of the temperature.

* Assisted by the U. S. Office of Naval Research.
[1] G. S. Rushbrooke, Trans. Faraday Soc. **36**, 1055 (1940).

QA11. Can a Well-Informed Heat Engine (WHE) Have Free Will? JEROME ROTHSTEIN, *Columbia University.*—WHE defined: physical system with measuring apparatus, effector apparatus to operate on environment and self, and internal programming whereby operations are performed on environment and self as a function of information input and internal state. Theorem: arbitrary operationally defined behavior is realizable in principle by WHE.[1] Query: within WHE's universe U (close system containing WHE) can WHE perform measurements permitting him to predict his future behavior? Answer: no. Proof: WHE interacts with rest of U so prediction of WHE behavior requires determination of state ϕ of U. Initial less perfect knowledge of U corresponds to entropy $S(U)>S(\phi)$, in fact $S(\phi)=0$ for pure state required for prediction. If answer yes, 2nd law violated, therefore no. Conclusion: it is impossible for a WHE contained in a closed system to decide, on the basis of measurements made by means wholly contained in the system, between the alternatives (a) the behavior of WHE is determinate (b) the behavior of WHE is indeterminate, i.e., relative to U WHE has "free will."

[1] J. Rothstein, Phys. Rev. **86**, 620(A) (1952).

FRIDAY EVENING AT 7:00

Shoreham, Main Ballroom

(H. A. BETHE presiding)

Banquet of the American Physical Society

After-dinner speakers: E. R. PIORE AND P. DEBYE

SATURDAY MORNING AT 9:30

Shoreham, Main Ballroom

(H. A. BETHE presiding)

Symposium on Polarization of Nucleons by Scattering

R1. High-Energy Experiments on Polarization of Protons. CLYDE WIEGAND, *University of California, Berkeley.* (30 min.)

R2. Polarization of High-Energy Protons. JOHN MARSHALL, *University of Chicago.* (30 min.)

R3. Polarization in Neutron-Proton Collisions. JOHN TINLOT, *University of Rochester.* (30 min.)

R4. Theoretical Considerations about Polarization Experiments. LINCOLN WOLFENSTEIN, *Carnegie Institute of Technology.* (30 min.)

SATURDAY MORNING AT 9:30

Sheraton Park, Continental Room

(H. H. BARSCHALL presiding)

Neutron Physics, II; Neutron Resonances

RA1. Total Neutron Cross Sections in the Kilovolt Region: Tl^{203} and Tl^{205}.* J. H. GIBBONS AND H. W. NEWSON, *Duke University.*—The use of a high-resolution neutron collimation-detection system,[1,2] used in conjunction with a Van de Graaff accelerator and the $Li^7(p,n)$ reaction, has been successful in the isotopic assignment of several Tl resonances in the region 3–80 kev neutron energy. For example, the resonance at 5 kev seems to be due to Tl^{203}, whereas the 17.5-kev peak and at least one peak between 50 and 60 kev are due to Tl^{205}. The Tl^{205} average level spacing seems to be several times that of Tl^{203}. The enriched Tl^{203} sample, which made these measurements possible, was loaned by the Stable Isotopes Division, Oak Ridge National Laboratory. Time permitting, other recent measurements will be presented.

* Work supported by the U. S. Atomic Energy Commission.

[1] J. H. Gibbons and H. W. Newson, Phys. Rev. **91**, 209A (1953).

[2] J. H. Gibbons, Bull. Am. Phys. Soc. **29**, 36 (1954).

RA2. Neutron Capture Measurements with the G. E. Betatron Velocity Selector. R. D. ALBERT, M. L. YEATER, AND E. R. GAERTTNER, *Knolls Atomic Power Laboratory.**—The capture of neutrons in a sample is measured by time coincidence detection of the emitted capture photons.[1] Level densities thus obtained are

Sample	Au	Mo	Ta	Sm_2O_3	Gd_2O_3
Number of levels	7	4	13	16	9
Energy range (ev)	58–186	43–153	10–100	8–95	20–62

Levels separated by 4 ev at 100 ev are resolved. The observed counting rate of photons emitted by a sample having a ratio σ_c/σ_T of capture to total cross section is given by $f(E)\langle\eta^2V(V-1)\rangle_{Av}\sigma_c/\sigma_T(1-\bar{T})$ where $f(E)$ is the neutron intensity, η the detector efficiency, V the gamma-ray multiplicity, and $\bar{T}$ is the transmission broadened by instrumental resolution. This relation is valid as long as a neutron scattered in the target has small probability of being subsequently capture. The factor $f(E)\langle\eta^2V(V-1)\rangle_{Av}$ is determined by a low-energy measurement where $\sigma_c \simeq \sigma_T$, and $\bar{T}=0$. $f(E)$ is measured with a boron counter. On the assumption that $\langle\eta^2V(V-1)\rangle_{Av}$ is independent of energy, one obtains $\Gamma_\gamma/\Gamma(1-\bar{T})$ as a function of energy for each resonance. Conventional procedures developed for area analysis of transmission data may be applied to obtain resonance parameters.

* Operated by the General Electric Company for the U. S. Atomic Energy Commission.

[1] R. D. Albert and E. R. Gaerttner, Phys. Rev. **91**, 451(A) (1953).

RA3. Resonance Scattering of Ag and Au.* R. E. WOOD,† *Brookhaven National Laboratory.*—The resonance scattering of Ag and Au has been measured below 10 ev, using thin samples and the scattering pipe technique of Borst.[1] On the basis of the observed scattering data and the available total cross section data, the total angular momentum of the compound nucleus in the resonant state has been uniquely determined as follows: $I=1$ ($g=\frac{3}{4}$) for the 5.2-ev resonance of Ag, and $I=2$ ($g=\frac{5}{8}$) for the 4.91-ev resonance of Au. These assignments are in disagreement with the results of Tittman and Sheer[2] in the case of Au, and are in agreement with the results of Sheer *et al.*[3] in the case of Ag. The method of analysis will be given and parameters of the resonances will be discussed.

* Research performed under the auspices of the U. S. Atomic Energy Commission.

† Doctoral candidate from the University of Utah.

[1] L. B. Borst, Phys. Rev. **90**, 859 (1953).

[2] J. Tittman and C. Sheer, Phys. Rev. **83**, 746 (1951).

[3] Sheer, Moore, Rainwater, and Havens, Columbia Nuclear Physics Progress Report, June 1952.

RA4. Self-Indication Measurement of σ_{to} for the 5.2-ev Neutron Resonance in Silver.* J. E. DRAPER AND C. P. BAKER, *Brookhaven National Laboratory.*—This measurement was made using the pulsed 60-inch cyclotron to deliver a neutron burst of 0.7 μsec in each 540 μsec interval, and a 64 channel time-of-flight analyzer to distinguish neutron energies. The detector was a thin silver (n,γ) radiator viewed by six shielded NaI gamma detectors (in fast twofold coincidence to minimize background which was 0.03 of the resonance peak with thick samples). The counting rate *vs.* neutron flight time over a 4.3-meter flight path was taken (a) with only the silver radiator in position and (b) with the addition of the same thickness of silver absorber in good geometry. The ratio of the areas in the resonance for (b) and (a) constitutes the transmission which depends only on σ_{to} and not on the width Γ. Six silver thicknesses were used ranging $N\sigma_{to}$ from 0.24 to 120 to check the fit of data with theory. Preliminary analysis gives $\sigma_{to}=33\,000\pm3000$ barns (isotopic). The analysis of data taken at a resolution of 0.2 μsec/m for silver resonances up to 100 ev is in progress. The influences of Doppler broadening, scattering in the radiator, and wing area will be discussed.

* Research performed under contract with the U. S. Atomic Energy Commission.

RA5. Measurements of Neutron Resonance Parameters in U, Th, Hg, and Au.* J. S. LEVIN AND D. J. HUGHES,† *Brookhaven National Laboratory.*—Several neutron resonances in U, Th, Hg, and Au have been investigated with the Brookhaven fast chopper and their parameters determined. Three methods of analysis were used; "shape" analysis, "area" analysis, and a method[1] based on an analysis of the interference between resonance scattering and potential scattering. All of these analyses are corrected for the effects of Doppler broadening. The parameters of the 6.70 ± 0.06-ev resonance in U^{238} were found to be $\sigma_0=23\,000\pm3000$ b, $\Gamma=25\pm2$ mv, $\Gamma_n=1.5\pm0.1$ mv, $\sigma_0\Gamma=595\pm30$ bev, $\sigma_0\Gamma^2=15.2\pm0.7$ bev.[2] The radiation width of this level is therefore 23.5 ± 2 mv, which is the smallest value reported for any resonance. The 22, 24, and 71-ev resonances in Th^{232} also have very small radiation widths. The 4.9 and 61-ev levels in Au^{197}, and the 23-ev level[2] in Hg^{198} of Γ_γ on atomic weight in this group of elements indicates that radiation widths are influenced by nuclear shell structure.

* Work carried out under contract with U. S. Atomic Energy Commission.
† At present a Fulbright Professor at Cambridge University.
[1] Kato, Hughes, and Levin, Phys. Rev. **93**, 930 (1954).
[2] Isotopic assignment of this resonance made by L. M. Bollinger, private communication.

RA6. Parameters of Neutron Resonances in Cs, In, Sn, Pr.* R. S. CARTER AND J. A. HARVEY, *Brookhaven National Laboratory.*—The neutron resonance cross section structure of cesium, indium, tin, and praseodymium has been investigated in the energy interval 3 to 400 ev using the Brookhaven fast chopper. Wherever possible thick and thin samples were run to determine Γ from which a value for Γ_γ could be obtained. The average Γ_γ for each element was obtained and used in the calculation of Γ_n for each resonance. The ratio of the average reduced neutron width to the average level spacing per spin state $(\bar{\Gamma}_n^0/\bar{D})$ was determined for each element. Ten resonances were found below 300 ev in Cs^{133}. For the seven resonances below 160 ev, $\bar{D}=50$ ev per spin state and $\bar{\Gamma}_n^0/\bar{D}=0.7\times10^{-4}$. Twenty-two resonances were found below 150 ev in normal indium (4.2 percent In^{113}, 95.8 percent In^{115}). Below 50 ev, $\bar{D}=17$ ev per isotope and spin state. Separated isotopes of In are now being studied. Seven resonances were found below 150 ev in normal tin. One is in Sn^{119}, two in Sn^{117}, one in Sn^{116}, and none in Sn^{120}. The remaining three have not yet been identified. The large spacing agrees with the results obtained at 1 Mev.[1] Four resonances were found in Pr below 360 ev giving a value for $\bar{D}$ of about 200 ev per spin state.

* Work carried out under contract with the U. S. Atomic Energy Commission.
[1] Hughes, Garth, and Levin, Phys. Rev. **91**, 1423 (1953).

RA7. Neutron Resonances in Holmium, Thulium, and Lutetium.* V. E. PILCHER, R. S. CARTER, AND A. STOLOVY, *Brookhaven National Laboratory.*—Neutron transmission measurements of holmium, thulium, and lutetium in the energy region 3–300 ev have been carried out using the Brookhaven fast chopper. With the present resolution it is felt that all resonances have been resolved up to 100 ev. It has been possible to analyze most of the observed resonances for the individual Breit-Wigner parameters by making use of two different sample thicknesses. The analysis, in all cases, is based on the measurement of the area above a transmission dip, with corrections for Doppler broadening. In holmium, 19 resonances have been observed, giving an average level spacing $(\bar{D})$ of 12 ev per spin state. A value of Γ_n has been calculated for each resonance, making use of a best value of Γ_γ (assumed constant). The ratio $\bar{\Gamma}_n^0/\bar{D}$ for holmium is found to be 2.8×10^{-4}. In thulium, 17 resonances were found, giving an average level spacing of 14 ev per spin state. Preliminary calculations give a $\bar{\Gamma}_n^0/\bar{D}$ of 1.7×10^{-4}. Analysis of data on lutetium is now in progress.

* Work carried out under contract with U. S. Atomic Energy Commission. These samples were loaned to us by Dr. F. H. Spedding of the Ames Laboratory.

RA8. Variation of the $\bar{\Gamma}_n^0/\bar{D}$ Ratio with Atomic Weight.* J. A. HARVEY, C. E. PORTER, AND D. J. HUGHES,† *Brookhaven National Laboratory.*—The black-nucleus model[1,2] predicted a value of $\sim1.4\times10^{-4}$ for the ratio of the average of the reduced neutron width of low-energy neutron resonances for a given spin state of the compound nucleus to the average of the level spacing of that spin state. According to several recent theories[3–5] this ratio depends upon the size of the target nucleus and has pronounced maxima at atomic weights corresponding to size-resonances. In the cloudy-crystal-ball model[3] this ratio can vary from about $(0.2\text{–}8)\times10^{-4}$. A careful study has been made of the parameters of the resonances up to 100–200 ev for many nuclei above atomic weight 100. A peak in the width-to-spacing ratio of only twice the black-nucleus value is found about mass 160. Around mass 120 and above mass 190 the ratio is 0.8×10^{-4}. A discussion of this discrepancy will be given.

* Work carried out under contract with the U. S. Atomic Energy Commission.
† At present a Fulbright Professor at Cambridge University.
[1] Feshbach, Peaslee, and Weisskopf, Phys. Rev. **71**, 145 (1947).
[2] H. Feshbach and V. F. Weisskopf, Phys. Rev. **76**, 1550 (1949).
[3] Feshbach, Porter, and Weisskopf, U. S. Atomic Energy Commission Report NYO-3076, 1953 (unpublished).
[4] A. Bohr and B. R. Mottelson, Danske Vidensk. Selskab. Mat.-fys. Medd. **27**, No. 16 (1953).
[5] R. G. Thomas, private communication.

RA9. Analyses of Neutron Resonances in the Zinc Isotopes. D. A. DAHLBERG AND L. M. BOLLINGER, *Argonne National Laboratory.*—Using the Argonne fast neutron "chopper," measurements have been made on the cross section of normal zinc and samples enriched in Zn^{64}, Zn^{68}, Zn^{67}, and Zn^{65} over the energy range from 150–10 000 ev. An isotopic assignment was made for all resonances observed in normal zinc. Resonance widths Γ were obtained by finding values of Γ which give calculated areas above the transmission dips that are equal to the experimentally measured areas, and by curve fitting using the Breit-Wigner one-level formula. The results obtained are shown in Table I. No resonances were observed in Zn^{66} below 10 kev.

TABLE I.

E_0	Isotopic assignment	g (assumed)	Γ
225 ev	67	$\frac{1}{2}$	1.3 ev
455	67	$\frac{1}{2}$	10
530	68	1	10
1620	67	$\frac{1}{2}$	19
2300	67	$\frac{1}{2}$	29
2750	64	1	70
4600	64	1	56

RA10. Total Neutron Cross Sections of Bi and Mn. L. M. BOLLINGER, R. R. PALMER, AND D. A. DAHLBERG, *Argonne National Laboratory.*—The Argonne fast neutron "chopper" was used to measure the total neutron cross sections of Bi and Mn in the energy range 200 to 10 000 ev. In Bi, the resonances at 810 and 2370 ev, for which widths of 5.3 and 19 ev were measured, were both observed to have the characteristic S-wave scattering shape. For manganese, the first three resonances at 337, 1080, and 2360 ev, were intensively studied. Assuming S-wave scattering, the measured peak cross section of the 2360-ev resonance implies that its J value must be 3. An unusual behavior was observed for the cross section in the neighborhood of the 1080-ev resonance which can be interpreted as being caused by interference between resonances. This interpretation implies $J=3$ for the 1080-ev level and $J=2$ for the 337-ev level. Cross-section curves calculated with the above J assignments reproduce every qualitative feature of the measured curves, but no choice of level widths gives

complete quantitative agreement. In particular, the width required to fit the data near the base of the 337-ev resonance is greater than that needed near its peak.

RA11. Further Applications of the "Internal Source" Scintillation Spectrometer. E. DER MATEOSIAN, *Brookhaven National Laboratory.**—"Internal source" scintillation spectrometry is performed by means of the usual methods of scintillation spectrometry with the exception that a NaI—Tl crystal is used in which is dissolved the source of radiations under investigation. Obvious advantages of incorporating the radioactive material into the crystal are that one obtains a 4π geometry, almost 100 percent efficiency for ionizing particles and soft photons and the absence of "window" and source thickness corrections. In previous publications we have described the application of this technique to the study of two-step isomeric transitions, beta decay, alpha-particle decay, and L and K orbital electron capture. The method has now been used to determine the neutron capture cross section for the recently observed successive neutron capture in Ta^{181}; i.e., $Ta^{181}+n\rightarrow Ta^{182}+n\rightarrow Ta^{183}$. A comparison of the amounts of Ta^{182} and Ta^{183} formed allows one to calculate a value for the neutron capture cross section for the second step, which we find to be $59\,000\pm10\,000$ barns. A further application has been made to the study of Cd^{113m} which decays by means of the emission of a 575-kev beta ray.

* Work accomplished under the auspices of the U. S. Atomic Energy Commission.

RA12. Neutron Multiplicity from Spontaneous Fission of Uranium. K. W. GEIGER AND D. C. ROSE, *Research Council of Canada.*—Metallic uranium[1] was placed in a paraffin pile containing two $^{10}BF_3$ neutron counters. The amplifier was blocked by a gate circuit which opened for 320 μsec after the first neutron of an event was collected. This time is about twice as long as the mean life of thermal neutrons in the pile. The number of neutrons during this interval was recorded and gives therefore information concerning the actual number of neutrons released in one fission event. The efficiency of the pile was found using the known neutron rate from spontaneous fission of U, 1.65×10^{-2} neutrons sec^{-1} g^{-1}.[2] Without further assumptions the method does not give the mean neutron multiplicity directly but the higher moments of the multiplicity spectrum. A Poisson distribution for the multiplicity spectrum fits our data well and gives an average of 2.2 ± 0.2 neutrons per spontaneous fission. This value is in good agreement with the mean multiplicity from other methods.

[1] Loaned by Atomic Energy of Canada Limited.
[2] D. F. Littler, Proc. Phys. Soc. (London) **A65**, 203 (1952).

SATURDAY MORNING AT 9:30

Shoreham, West Ballroom

(BRUNO ROSSI presiding)

Cosmic Rays

S1. Galactic r-f Radiation and Cosmic-Ray Electrons.* S. B. TREIMAN AND M. BLUME, *Princeton University.*—It has been suggested[1] that our spiral arm is permeated by a magnetic field directed along the arm and of magnitude $\sim6\times10^{-6}$ gauss. Such a field would cause cosmic-ray electrons to radiate, partly in the radio-frequency range. A calculation of this effect has been made for an assumed electron energy spectrum of the form const$\times E^{-2}$, with a "cutoff" at 1.5 Bev. (The results are not sensitive to the choice of the exponent.) Comparison with the observed r-f intensities coming from the galactic background leads us then to an estimate of f_{max}, the upper limit on the fraction of electrons in the cosmic radiation. We find $f_{max}\approx0.2$. Inasmuch as direct measurements give an upper limit of only a few percent,[2] this result is not in itself very interesting. However, we point out that for the magnetic field configuration envisaged in reference 1, the bremsstrahlung should be strongly polarized. The apparent experimental absence of polarization permits us then to lower the estimate of f_{max} by at least an order of magnitude, limited only by the accuracy of polarization measurements.

* Supported in part by the U. S. Office of Naval Research and the U. S. Atomic Energy Commission.
[1] S. Chandrasekhar and E. Fermi, Astrophys. J. **118**, 113 (1953).
[2] Critchfield, Ney, and Oleska, Phys. Rev. **85**, 461 (1952).

S2. Acquirement of Cosmic-Ray Energies by Betatron Action.* W. F. G. SWANN, *Bartol Research Foundation.*—In a cylindrically symmetrical problem with magnetic field along the axis of z and changing with time, the energy of a particle is shown to increase continually if $E-\dot{r}H/c$ is greater than zero, E being the tangential electric field, and $\dot{r}$ the radio velocity. It follows, moreover, that if $E>H$, a particle can never loop except around the origin of symmetry. The situation is discussed in relation to galactic magnetic fields. Spacial conductivity plays a role in cosmic-ray problems concerning acquirement of energy. It is pointed out that there is an upper limit nec to the spacial current density where n is the number of ions per cc, and e is the electronic charge. The implication of this limitation in cosmic-ray problems is discussed.

* Assisted in part by the joint program of the U. S. Office of Naval Research and the U. S. Atomic Energy Commission.

S3. Solar-Connected Variations of the Cosmic Rays. P. MORRISON, *Cornell University.*—Three apparently distinct variations of cosmic-ray intensity in time can be ascribed to solar phenomena: (1) large sudden increases of low-energy cosmic-rays at the time of exceptional solar flares, (2) world-wide decreases in cosmic-ray intensity, lasting for days, and correlated roughly with magnetic storms, (3) irregular maxima and minima showing a marked *27d* recurrence. The Chicago group has demonstrated that the increases of type (1) correspond to cosmic-ray particles emitted from roughly the solar direction and that less extreme flares also emit cosmic-ray particles but in smaller numbers. Events of type (2) can be explained as the consequences of emission from the active sun of diffuse clouds of ionized hydrogen bearing a turbulent magnetic field. If such clouds are sufficiently large and carry appropriate fields they will sweep the interplanetary volume free of cosmic-ray particles, which randomly diffuse into the clouds until steady-state density is reached. With parameters reasonable for these events, the steady state is reached in days. The observed decreases are interpreted as times when the earth is immersed in such an empty cloud. Similar, but less unusual clouds emitted from solar active regions, and partly filled at formation with solar-flare generated cosmic-rays, can account for type (3) changes as well.

S4. Storm Decrease of the Cosmic Radiation at the Pole. S. F. SINGER, *University of Maryland.*—A large decrease in the cosmic-ray intensity has been observed in the immediate vicinity of the geomagnetic pole for the first time, in association with similar variations at other geomagnetic latitudes. Hence the explanation of the cosmic storm decrease in terms of a magnetic redistribution due to an equatorial ring current becomes quite unlikely. It is possible to account for the effect either by a general deceleration of the cosmic radiation in the vicinity of the earth or by a decrease in their number or by both. Experiments will be discussed which may allow one to distinguish among these possibilities.

S5. The Flux of Primary Cosmic-Ray Heavy Nuclei at the Equator. R. F. HOURD, J. R. FLEMING, AND J. J. LORD, *University of Washington.*—Nuclear emulsions have been exposed in the stratosphere in connection with the U. S. Office of Naval Research sponsored project Churchy. The plates were exposed by Skyhook balloon for 6.6 hours at elevations from 90 000 to 94 000 feet and at geomagnetic latitude 10°N. A sandwich of 6 Ilford G-5 emulsions 600 microns in thickness were employed having only thin tissue paper between adjacent emulsions. The sandwich of emulsions with surfaces vertical were placed in a thin aluminum container along with thermal insulation. The outside plates of the sandwich were scanned for heavy tracks. The tracks were then identified by range, delta rays, grain counting, and the photoelectric determination of their width. Making corrections for geometry and absorption, the primary flux of particles having $Z \geq 10$ was found to be 0.44 ± 0.08 per sterad per second per square meter. The corresponding flux of C, N, O, and F nuclei was 2.3 ± 0.5. In addition, while it is difficult to make corrections for secondary Li, Be, and B it does appear that their relative abundance is even slightly greater than that reported by the Bristol group for latitude 55°N.

S6. A Čerenkov Counter Measurement of Fast Multiply Charged Cosmic Rays.* JOHN LINSLEY, *University of Minnesota.*—Additional results have been obtained with an improved version of the Čerenkov counter-cloud chamber apparatus which yielded a recently reported measurement of the flux of primary cosmic-ray alpha particles.[1] Instead of merely triggering the cloud chamber, the Čerenkov counter signals were displayed on a cathode-ray tube which was intensified by a gate from the geometry-defining Geiger-counter telescope so that pulse heights were recorded on continuously moving film. Sufficiently large gated signals, triggered the cloud chamber, provided it was sensitive at the time, so the event that caused the signal could be examined in some detail in such cases. Use of a larger multiplier permitted more rapid accumulation of data, and steps were taken to reduce perturbation of the flux that was measured by the material in the apparatus. Data were obtained during two Skyhook balloon flights at geomagnetic latitude 40°. The flux of fast alpha particles at that latitude will be reported, and information will be presented relating to primaries with Z greater than two.

* The research was supported in part by the joint program of the U. S. Atomic Energy Commission and the U. S. Office of Naval Research.
[1] Bull. Am. Phys. Soc. **29**, 59 (1954).

S7. Fragmentation of Heavy Primary Nuclei of the Cosmic Radiation into Light Elements.* J. H. NOON AND M. F. KAPLON, *University of Rochester.*—Interactions of heavy primary nuclei with carbon, oxygen, and hydrogen nuclei of plastic (cellulose acetate) have been studied to determine the proportion of light elements (Li,Be,B) produced as fast fragments. A vertical stack of stripped emulsions and plastic sheets was flown at Minnesota (55° geomagnetic) for 9 hours at 102 000 ft. Twelve 400μ Ilford G-5 emulsions (6 in.×4 in.), 11 200μ G-5–200μ G-0 emulsions and 11 plastic sheets were arranged in 11 sets of triads. In tracing 800 heavy primaries ($Z \geq 6$) through the stack, 15 interactions were found to occur in the plastic and in 8 cases light elements were produced as fast fragments. The probability for fragmentation into light elements thus obtained agrees with a previous calculation on the basis of a simple geometrical model using data from heavy primary interactions with nuclei of photographic emulsion.[1] This information is important in estimating what proportion of the observed flux of light elements at a given depth in the atmosphere comes from interaction of heavy primaries with nitrogen and oxygen of the residual atmosphere.

* This research was supported in part by the U. S. Air Force under Contract AF 18(600)-380 monitored by the Office of Scientific Research, Air Research and Development Command.
[1] Noon, Kaplon, and Ritson, Phys. Rev. **92**, 1585 (1953).

S8. The Interaction of Cosmic-Radiation Heavy Primaries in Lead.* Y. EISENBERG, *Cornell University.*—An emulsion "cloud chamber" consisting of lead plates and photographic emulsions was flown for 10 hours at a depth of 18 g/cm^2 from the top of the atmosphere. 508 tracks of primaries of charge $Z \geq 6$ traversing a total amount of 16 meters of lead were followed through the entire stack and the interaction mean free path was measured as a function of the mass number of the incident particles. The best fit to the experimental points is obtained by assuming a geometric cross section $\sigma = \pi(R_1 + R_2)^2$, $R = R_0 A^{\frac{1}{3}}$ and $R_0 = 1.2 \times 10^{-13}$ cm the interactions were studied in greater detail. The energy spectrum of the primary radiation was determined, the fragmentation of the incident particles was measured, and the relative abundance of the various charge groups at the top of the atmosphere was deduced.

* Supported in part by the U. S. Atomic Energy Commission and the U. S. Office of Naval Research.

S9. Nuclear Size and Cross Sections at Cosmic-Ray Energies.* ROBERT W. WILLIAMS, *Princeton University.*—Recent measurements of the absorption cross section of various nuclei for 1.4-Bev neutrons[1] have yielded nuclear radii which are quite close to those inferred from the electromagnetic experiments. The results of several cosmic-ray investigations have shown that cross sections for neutrons and protons in the "penetrating-shower" region (energy up by one order of magnitude) are consistently larger than could be inferred on a uniform-density nuclear model A nonuniform model ("fuzzy edge") is used here to reconcile partially the two sets of data and infer a nucleon-nucleon cross section in the high-energy domain.

* Supported by the U. S. Office of Naval Research and the U. S. Atomic Energy Commission.
[1] Hill, Coor, Hornyak, Smith, and Snow, Bull. Am. Phys. Soc. **29**, 54 (1954).

S10. Observations on the High-Energy Soft Cascade.* M. KOSHIBA AND M. F. KAPLON, *University of Rochester.*—The use of stripped emulsion stacks affords an excellent opportunity to study the soft cascade process in detail. In order to specify with some certainty the initial conditions of the cascade and to introduce no selection bias, it is appropriate to study the soft showers originating from the decay photons of neutral π mesons emitted in high-energy nuclear interactions. Soft showers which appear to originate from a single electron or photon in the emulsion may be accompanied by one or more photons; further, for these showers there may be a detection bias favoring those showers with the largest fluctuations.

We have studied the soft cascades initiated by the decay π^0 photons of a very high-energy nuclear interaction. For the showers of low initial energy the cascade seems to develop in accord with the predictions of shower theory; on the other hand for showers of very high initial energy ($\gtrsim$100 Bev), the trident process seems to play an important role in the initial

development.[1] Detailed shower developments will be presented and the trident process discussed.

* This research was supported in part by the U. S. Air Force under a contract monitored by the Office of Scientific Research, Air Research and Development Command.

[1] Evidence for this was presented by Dr. P. Freier at the Duke Conference on Cosmic Radiation.

S11. Cross Sections for Meson-Induced Stars in Ilford G5 Nuclear Emulsions.* LEONARD A. MANN, RAY A. GRANDEY, AND ARNOLD F. CLARK, *Carnegie Institute of Technology.*—Ilford G5 plates were exposed to pion beams of various energies. The mean free paths and prong distributions for the stars formed in the emulsion are listed in Table I. The negative

TABLE I.

Pion	Energy (mev)	No. of stars	Mean free path (cm)	Average No. of prongs per star
π^+	110	369	33.6±1.7	3.1
π^-	110	349	...	2.7
π^+	155	400	31.1±1.7	3.2
π^-	155	1454	27.9±1.7	2.6
π^-	210	770	29.8±0.9	3.0

pion plates were "area scanned," the positive pion plates were scanned linearly. The total cross section corrected for the Coulomb barrier, taken at 10 Mev, is constant within statistical error. The errors quoted are standard deviations based upon the number of stars and the estimate of the length of track scanned.

S12. Cosmic-Ray μ Meson—Low-Energy Differential Range Spectrum.* A. FAFARMAN AND M. H. SHAMOS, *New York University.*—The differential range spectrum of cosmic-ray μ mesons has been investigated in the region from 0 to 410 gm/cm² Pb. The apparatus comprised a GM counter tray "*A*" (30×50 cm²) and a 3-liter tank of liquid scintillator "*B*" (15 cm diameter×20 cm deep) with variable thickness of absorber between the two. Delayed coincidences *A B B* (delayed 0.5 to 8.0 μsec) were used to identify mesons stopping in the tank; for each such event the delay between *B* and *B*(delayed) was recorded by a 4 channel delay discriminator. The possibility of a contribution to the counting rate from the photomultiplier after-pulsing was investigated and found to be zero. The spectrum decreases monotonically with decreasing energy and shows no irregularity: (several minima have been observed in this portion of the spectrum by investigators using the anticoincidence method which they attributed to electrons and/or protons). Although only relative readings were taken, the method is adaptable to a precision determination of the *absolute* differential range spectrum of low-energy mesons, a region of the spectrum where some uncertainty exists.[1] The delay data yields for the natural mixture of sea level cosmic-ray μ mesons a mean life in carbon of 2.14±0.07 μsec.

* Research assisted by the U. S. Atomic Energy Commission and the U. S. Office of Naval Research.

[1] C. M. York, Phys. Rev. **85**, 998 (1952).

S13. Pairs Formed by Bremsstrahlung of Great Energy. I. Experimental. D. T. KING AND M. M. BLOCK,* *Naval Research Laboratory.*—In cosmic-ray experiments on electromagnetic phenomena of high energy there is a possibility of confusion between electron pairs created directly by fast electrons[1] (tridents) and bremsstrahlung pairs materializing indistinguishably close to the track of the parent particle. In nuclear emulsions, pairs originating within ~0.2 micron from their parent track are generally unresolvable from tridents. In order to examine this effect, we have measured for 200 examples the projected orthogonal distance between the origin of a bremsstrahlung pair and the nearest thin parallel track. Twenty-six emulsions were exposed to the cosmic radiation at altitudes exceeding 95 000 ft at geomagnetic latitude 55°N for six hours. The energies of the incident electrons considered were between 0.1 and 10 Bev. The experimental proximity distribution has been compared to the theoretical distribution to be described in the following paper. From these data we estimate the fraction of apparent tridents among the bremsstrahlung pairs to be about 6 percent.

* On military leave of absence from Duke University, Durham, North Carolina.

[1] Hooper, King and Morrish, Phil. Mag. **42**, 304 (1951).

S14. Pairs Formed by Bremsstrahlung of Great Energy. II. Theoretical Separation Distribution. M. M. BLOCK* AND D. T. KING, *Naval Research Laboratory.*—The distribution in orthogonal separation between the point of materialization of a bremsstrahlung pair and the track of the parent electron has been derived. Since the major contribution to the proximity distance in nuclear emulsions usually arises from the multiple coulomb scattering of the parent particle, we have not considered the angle of emission due to the radiative collision. The calculations have been made for the experimental conditions described in the preceding paper and satisfactory agreement with those results has been found. The analysis enables us to determine the fraction of bremsstrahlung pairs which materialize within a given distance from the path of the parent electron. The fraction experimentally unresolvable from tridents is found to increase rapidly with increasing energy of the incident particle. Thus, for a primary energy of 100 Bev and a path length of 0.5 radiation units in the emulsion, it is found that this fraction is ~70 percent.

* On military leave of absence from Duke University, Durham, North Carolina.

S15. Ratio of π^-/π^+ Meson Production in Cosmic-Ray Disintegrations of Emulsion Nuclei. HERMAN YAGODA, *National Institutes of Health.*—In the examination of 1–2 mm thick G5 emulsions[1] exposed in the stratosphere 531 σ stars and 121 $\pi\mu$ decays were observed to originate in stars or decay processes. The π^-/π^+ ratio exhibits a strong energy dependence. When corrected for π^- mesons which only produce neutrons and Auger electrons on capture, the variation with energy is

T_π (Mev)	0–5	7.5±2.5	12.5±2.5	27.5±12.5
π^-/π^+	16.1±2.6	5.4±0.8	3.6±0.7	2.4± 0.5

At the highest kinetic energies under consideration the π^-/π^+ ratio appears to approach 2, rather than unity as indicated by Mei and Pickup.[2] One example of the coplanar decay of a charged tau meson into three pions has been observed. Two of the secondaries terminate giving $E_{\pi^-}=3.9$ Mev and $E_{\pi^+}=29$ Mev. The energy of the third particle is estimated at 45±5 Mev from the grain density along 3400 microns of recorded track. The mass of the tau meson based on a Q value of 78±5 Mev is 984±10m_e.

[1] H. Yagoda, Phys. Rev. **85**, 891–900 (1952).
[2] J. V. Mei and E. Pickup, Can. J. Phys. **30**, 430–7 (1952).

SATURDAY MORNING AT 9:30

Sheraton Park, Burgundy Room

(W. W. BUECHNER presiding)

Reactions of Transmutation, II

SA1. Pickup Reactions $B^{10}(n,d)Be^9$ for 14-Mev Neutrons.* F. L. RIBE AND J. D. SEAGRAVE, *Los Alamos Scientific Laboratory.*—Measurements have been made of the yields and angular distribution of deuterons resulting from the bombardment of B^{10} by 14-Mev neutrons. The spectrum of charged reaction products was measured by means of a coincidence-telescope spectrometer consisting of two proportional counters and a thin NaI scintillator. The telescope was rotated to obtain measurements at various angles. Deuterons corresponding to the ground state and 2.43-Mev excited state of Be^9 were identified by measurements of both their energy and dE/dx values. The ground-state angular distribution was found to match the expected Butler inverse-stripping curve for $l_p=1$. The Butler analysis for the excited-state deuterons also gave $l_p=1$, corresponding to odd parity and spin 3/2, 5/2, 7/2, or 9/2 for the first-excited state of Be^9. In particular, the spin value 1/2, to be expected from the $L-S$ coupling model, is excluded. The cross sections, integrated from zero to 90 degrees (center-of-mass), are 21 ± 3 and 16 ± 2 millibarns, respectively, for the ground- and excited-state reactions.

* Work done under the auspices of the U. S. Atomic Energy Commission.

SA2. Cross Sections for the Reactions $C^{12}(p,pn)(n,2n)C^{11}$. S. D. WARSHAW, R. A. SWANSON, AND A. H. ROSENFELD, *The University of Chicago.*—The cross section for the reaction $C^{12}(p,pn)C^{11}$ has been measured at two energies, one above and one below that at which a dip has been observed at Berkeley.[1] At 387 ± 16 Mev the cross section is 43.6 ± 2.2 mb. This value does not fall on an extrapolation of the Berkeley result. However, at 283 ± 14 Mev we find 48.9 ± 2.5 mb which agrees with Berkeley within experimental error. The error of our experiment comes almost entirely from the uncertainty of the calibration of the C^{11} counter. The reproducibility of a single measurement was better than 1 percent so that the relative slope of the cross section as a function of energy is accurately determined. Using the same C^{11} counting techniques, the cross section for the $(n,2n)$ reaction is found to be 17.9 ± 1.4 mb for the Chicago neutron beam. For this beam, studied by Yodh,[2] the energy region from 300 to 440 Mev contains about one-half the neutron flux—peaked at about 400 Mev—with the remainder nearly uniformly distributed down to 20 Mev. This cross section may be compared with 20.0 ± 4 mb for a spectrum peaked at 90 Mev[3] and indicates that the cross section is probably nearly constant with energy.

[1] Aamodt, Petersen, and Phillips, Phys. Rev. **88**, 739 (1952).
[2] G. B. Yodh (to be published).
[3] R. L. Mather and H. F. York, quoted in reference 1. See also McMillan and York, Phys. Rev. **73**, 262 (1948).

SA3. Excitation Function for $C^{12}(D;\ p,2n)C^{11}$, $C^{12}(He^3;\ 2p,2n)C^{11}$, and $C^{12}(\alpha;\ 2p,3n)C^{11}$.* W. BIRNBAUM AND W. E. CRANDALL, *California Research and Development Company,* G. P. MILLBURN AND R. V. PYLE, *University of California, Berkeley.*—The carbon-11 activity *versus* range for monoergic beams of 340-Mev protons, 190-Mev deuterons, 490-Mev He^3 particles, and 380-Mev alpha particles are compared and from the known attenuation cross section for these particles and the excitation function for $C^{12}(p,pn)C^{11}$ reaction,[1] similar excitation functions for the multi-nucleon particles are obtained.

* Supported by the U. S. Atomic Energy Commission.
[1] Aamodt, Petersen, and Phillips, Phys. Rev. **88**, 739 (1952).

SA4. Energy Levels of C^{12} by Inelastic Alpha Scattering.† D. W. MILLER, V. K. RASMUSSEN, AND M. B. SAMPSON, *Indiana University.*—The previously reported[1] investigation of the inelastic scattering of 22-Mev alpha particles by carbon has been extended. Recoil nuclei from elastic scattering and from inelastic scattering with excitation of the 4.43-Mev level have been observed at forward angles. No recoils in which the C^{12} had been excited to the 7.7-Mev level were observed. From the observed intensity of the corresponding inelastic alphas, the probability that a C^{12} nucleus excited to the 7.7-Mev state will decay to Be^8+He^4 is estimated to be greater than ~80 percent. At forward angles the alpha spectrum corresponding to 8 to 16 Mev excitation of C^{12} has been investigated. A weak group leaving C^{12} excited to 12.7 Mev and an intense broad group with several peculiar characteristics are observed. No other group with intensity greater than 10 percent that of the alpha group leaving C^{12} in the 9.6-Mev state can be detected above the continuum due to $C^{12*}\rightarrow Be^8+He^4$. The broad group is found only at angles less than 20°. It may possibly be explained by inelastic scattering, leaving C^{12} in a number of overlapping states between 9 and 11.7 Mev.

† Supported by the joint program of the U. S. Office of Naval Research and the U. S. Atomic Energy Commission.
[1] Rasmussen, Miller, Carmichael, and Sampson, Phys. Rev. **92**, 852 (1953).

SA5. Energy Levels in C^{14} and N^{14}.* R. D. BENT, R. W. BONNER, AND R. F. SIPPEL, *The Rice Institute.*—The gamma radiation from the bombardment of a 50 percent $C^{12}-C^{13}$ target with four-Mev deuterons has been measured with a lens-type pair spectrograph. The energies of internally converted pairs were measured with a resolution of 2.7 percent. Strong gamma-ray lines were observed at 3.10, 3.42, 4.96, 5.12, 5.74, 6.14, and 6.72 Mev. Weaker lines were observed at 3.7, 3.9, 4.48, 6.48, 7.11, and 7.37 Mev. The intensity of the 6.72-Mev line relative to that at 6.14 Mev was increased by a factor of 3 when the bombarding energy was increased from 2 to 4 Mev. A probable interpretation of the lines are: those at 3.10, 3.7, and 3.9 are from the reaction $C^{12}(d,p)^*C^{13}$; The line at 4.48 Mev from the reaction $C^{13}(d,\alpha)^*B^{11}$ or a cascade in $^*N^{14}$; the lines at 4.96, 5.12, and 5.74 from the reaction $C^{13}(d,n)^*N^{14}$; the line at 6.14 Mev from $C^{13}(d,p)^*C^{14}$. The radiation of the four highest energies may be either from excited states of C^{14} or N^{14}.

* Supported by the U. S. Atomic Energy Commission.

SA6. Resonances in Proton Bombardment of C^{14}. G. A. BARTHOLOMEW, F. BROWN, H. E. GOVE, A. E. LITHERLAND, AND E. B. PAUL, *Chalk River Laboratories.*—The Chalk River electrostatic generator has been used to study the reaction $C^{14}(p\gamma)N^{15}$. An elemental carbon target (25 percent enriched in C^{14}) was used. Gamma rays were detected in a 2 in. by 2 in. diameter NaI crystal and a Dumont 6292 photomultiplier. Gamma-ray resonances were found at proton energies of 0.36, 0.53, and 0.64 Mev corresponding to levels in N^{15} observed at 10.53, 10.69, and 10.80 Mev in the $N^{14}(dp)N^{15}$ reaction.[1] At each resonance the ground state γ ray and a peak corresponding to γ rays of about 5.3 Mev are easily distinguished. From the angular distribution of the ground-state γ ray it may be deduced that the 10.69 Mev state is $3/2-$ and that the 10.80-Mev state is probably $3/2+$. In the region of the known (pn) resonances ($Ep=1.17$, 1.31, 1.66 Mev) the ground-state γ

ray is observed but is not strongly resonant. The angular distributions of the ground-state γ ray and the emitted neutrons favor the assignment of $1/2-$ for the 1.17 Mev resonance.

[1] Sperduto, Buechner, Elkind, and Fader, Phys. Rev. **91**, 473 (1953).

SA7. Scintillation Counter Study of Gamma Rays from Proton Capture in Sodium. E. B. NELSON, E. H. GEER, AND R. R. CARLSON, *State University of Iowa.**—The spectrum of the gamma rays produced by the resonant capture of 305 kev protons by sodium[1] has been studied with a single crystal scintillation spectrometer having a resolution of 21 percent at 6 Mev, and with a three crystal pair spectrometer having a resolution of 7 percent at 6 Mev. Gamma-ray energies were determined with an accuracy of 2 percent and cascades were identified by coincidence measurements. The energies of the gamma rays and cascades are consistent with transitions between known levels of Mg^{24}. Goldberg *et al.*[2] have determined the spin and parity of the 11.99 Mev Mg^{24} capture state to be $2+$ by a study of the elastic scattering of alpha particles by Ne^{20}. Our results on the intensity of the gamma rays and their angular distribution are consistent with this assignment. We do not observe direct gamma transitions to the ground state nor alpha decay of the capture state, the alpha decay presumably being inhibited by barrier penetrability.

* Supported in part by the U. S. Atomic Energy Commission.
[1] H. Casson, Phys. Rev. **89**, 809 (1953).
[2] E. Goldberg (private communication).

SA8. Gamma-Ray Resonances in the Proton Bombardment of Na^{23}.* N. P. BAUMANN,† F. W. PROSSER, JR.,† AND R. W. KRONE, *University of Kansas.*—Previous work in this laboratory[1] failed to show any resonances in the Mg^{24} compound nucleus from 12.453 Mev to 12.667 Mev, with the exception of a resonance at $E_p=0.874$ Mev attributed to a Fl^{19} target contamination. This agreed essentially with the earlier work of Burling.[2] However, the elastic scattering of alpha particles from Ne^{20} at Wisconsin[3] has indicated resonances in Mg^{24} at 12.481, 12.499, 12.531, and 12.601 Mev. A careful resurvey of this region has shown several small resonances agreeing in part with those found at Wisconsin. Pulse-height distributions of the emitted gamma rays have been carried out with a single-crystal spectrometer for several of these resonances and gamma-ray energies have been assigned. Great care was taken to eliminate Fl^{19} contamination on the targets insofar as possible. The excitation curve, pulse-height distributions, and decay schemes will be shown and discussed.

* Work supported in part by the U. S. Office of Naval Research.
† National Science Foundation Predoctoral Fellows.
[1] Phys. Rev. (to be published).
[2] R. L. Burling, Phys. Rev. **60**, 340 (1941).
[3] E. Goldberg (private communication).

SA9. Some Spin Assignments and Partial Width Measurements of Resonances in S^{32} from the Reaction $P^{31}(p\gamma)S^{32}$. H. E. GOVE, E. B. PAUL, A. E. LITHERLAND, AND G. A. BARTHOLOMEW, *Chalk River Laboratories.*—The angular distributions of some of the gamma rays from the $P^{31}(p\gamma)S^{32}$ reaction have been measured at seventeen resonances[1,2] in the range of proton energies 0.5–2.5 Mev. The partial widths for emission of the gamma rays to the ground and first-excited states of S^{32} have been measured at twelve of these resonances. For six of the resonances at which the ground state transition is predominant the angular distribution is consistent with the assignment $J=1\pm$ for the compound state. The partial widths for these dipole transitions lie between 0.1 ev and 10 ev. In the case of the 1.89 Mev resonance the total width is 24 kev, which suggests formation by P-wave protons. This would indicate that the measured partial width of 5 ev for the emission of the ground-state gamma ray is the partial width for electric dipole emission.

[1] H. E. Gove and E. B. Paul, Phys. Rev. **92**, 852 (1953).
[2] Smith, Cooper, and Harris, Bull. Am. Phys. Soc. **29**, 12 (1954).

SA10. Capture Gamma-Ray Studies Using a Scintillation Coincidence Spectrometer. ARTHUR RECKSIEDLER AND BERNARD HAMERMESH, *Argonne National Laboratory.*—Utilizing a collimated neutron beam from the Argonne heavy water reactor and two NaI(Tl) crystals, coincident gamma rays from the reactions $Cl^{35}(n,\gamma)Cl^{36}$ and $Cd^{113}(n,\gamma)Cd^{114}$ have been studied. Previous studies indicated that several possible two-step branches were present in the capture gamma decay schemes of these isotopes.[1,2] One 20-channel and one single-channel pulse-height analyzer were used with a coincident circuit having a resolving time of 5 microseconds. In chlorine, the 0.778-Mev gamma ray was found to be in coincidence with the 7.77-Mev gamma ray. Another possible line was observed at 0.725 ± 0.010 Mev. Other two-step cascades which were confirmed were the 1.15 Mev–7.42 Mev and 1.59 Mev–6.98 Mev branches. In cadmium, the 0.558 Mev–8.48 Mev branch was confirmed. Since the instrument has poor resolution in the high-energy range compared with a pair spectrometer, the values assigned to the more energetic gamma-rays of the cascades are the values reported by Kinsey *et al.*

[1] B. Hamermesh and V. Hummel, Phys. Rev. **88**, 916 (1952).
[2] Kinsey, Bartholomew, and Walker, Phys. Rev. **85**, 1012 (1952).

SA11. (d,p) Reactions of Ca^{42} and Ca^{44}.† C. M. BRAAMS,* *M.I.T.*—Thin targets of calcium oxide have been bombarded with deuterons from the MIT–ONR electrostatic generator, and the spectra of protons emitted at 90 degrees to the incident beam have been observed with the annular magnetic spectrograph and Eastman NTA nuclear emulsions. Enriched samples of $CaCO_3$ were obtained from the U. S. Atomic Energy Commission; Ca^{42} was concentrated to 64 percent and Ca^{44} to 98 percent. Targets were made by evaporating CaO onto Formvar films. The Q value for the (d,p) reaction to the ground state of Ca^{43} is 5.70 Mev; we have seen excited states in Ca^{42} at 0.38, 0.61, 1.00, and 1.40 Mev. For Ca^{45}, the ground-state Q value is 5.19 Mev; excited states are seen at 0.18, 1.43, 1.89, 2.24, 2.39, and 2.84 Mev. Quoted numbers are accurate to ±0.02 Mev. We intend to make more accurate measurements and to extend this work to higher excitations.

† This work has been supported by the joint program of the U. S. Office of Naval Research and the U. S. Atomic Energy Commission.
* Fellow of the Elsevier Foundation, Amsterdam, The Netherlands.

SA12. Excitation Function for $Fe^{56}(n,p)Mn^{56}$.* J. TERRELL AND D. M. HOLM, *Los Alamos Scientific Laboratory.*—The $Fe^{56}(n,p)Mn^{56}$ cross section has been measured as a function of neutron energy in the ranges 3 to 5 and 12 to 18 Mev. It is planned to extend the energy coverage of these measurements. Preliminary data indicates a maximum cross section in the region 12 to 14 Mev. The cross section at 5 Mev is about 1 percent of this maximum value, and for lower energies decreases rapidly.

* Work done under the auspices of the U. S. Atomic Energy Commission.

SA13. (Abstract withdrawn.)

SA14. Measurement of (p,xn) Cross Sections in Bismuth. R. E. BELL, *McGill University.**—Absolute cross sections of the reactions $(p,3n)$, $(p,5n)$, $(p,6n)$, and $(p,7n)$ in bismuth have been measured for proton energies ranging from 20 to 85 Mev. Bismuth foils ($\sim$80 mg/cm^2) were irradiated in the circulating beam of the McGill synchrocyclotron, together with Teflon foils ($\sim$25 mg/cm^2) to serve as proton flux monitors through the known $C^{12}(p,pn)C^{11}$ cross section. The polonium electron-capture activities from the (p,xn) reactions in bismuth were determined absolutely by counting the $K-X$ rays with a thin NaI(Tl) counter. The C^{11} activity of the monitor foils was measured by counting the annihilation quanta with a NaI(Tl) counter of known efficiency. The overall accuracy is estimated at 15 percent. The $(p,3n)$ cross section plotted as a function of energy forms a nearly symmetrical curve peaking at 0.85 barn at 28 Mev, with a half width of 12.5 Mev, dropping to less than 10 percent of its peak value by 49 Mev. The $(p,5n)$ cross section has a peak of $\sim$0.75 barn at 49 Mev. The $(p,6n)$ and $(p,7n)$ cross-section peaks are somewhat lower, and decrease only slowly above 70 Mev. This unsymmetrical behavior shows the increasing importance of fast nucleon cascade processes as the energy is increased (see following abstract).

* On loan from Chalk River Laboratories.

SA15. Schematic Calculation of (p,xn) Cross Sections of Heavy Elements.* J. DAVID JACKSON, *McGill University.*—Calculations have been made of (p,xn) and (p,pxn) cross sections of heavy elements for energies up to 100 Mev. Complete compound nucleus formation was assumed for proton energies below 30 Mev, while at higher energies the reaction probabilities for the prompt (cascade) processes and the residual nucleus excitation distributions were taken from the Chalk River Monte Carlo calculations at 60 and 90 Mev.[1] The evaporation process was handled in a simplified manner, neglecting charged particle evaporation and assuming a constant nuclear temperature (this schematic model for evaporation can be solved essentially exactly). Averaging over the Monte Carlo distributions leads to the (p,xn) and (p,pxn) cross sections as functions of incident proton energy. Comparison with the experimental data for bismuth (see preceding abstract) shows that the theory and experiment can be brought into good general agreement at least up to $x=7$, by taking $R\cong 7.7\times 10^{-13}$ cm, $T\cong 1.85$ Mev while $B\cong 7.4$ Mev where R is the nuclear radius, T is the nuclear temperature, and B is the average neutron binding energy.

* Supported by Atomic Energy of Canada, Limited.

[1] McManus, Sharp, and Gellmann, Bull. Am. Phys. Soc. **28**, No. 6 (1953), and private communication.

SA16. The Angular Distribution of U^{235} Fragments from Neutron-Induced Fission as a Function of Incident Neutron Energy. J. E. BROLLEY, JR., W. C. DICKINSON, AND R. L. HENKEL, *Los Alamos Scientific Laboratory.*—We have employed a double ionization chamber to extend our previously reported investigations[1] to 20 Mev. A common high-voltage electrode served a Frisch-grid chamber and a parallel plate chamber. A 0.9 mg/cm^2 Au foil, on which was evaporated a 0.5 mg/cm^2 layer of $U^{235}O_2$, was mounted on the Frisch-grid side of the common electrode. This electrode was honeycombed with holes to serve as a collimator. Those fragments traversing the collimating passages created a gate pulse for the amplifier of the gridded chamber. Only coincident pulses in the two chambers were counted. To attain complete symmetry between the 0° and 90° angular settings, the collimator holes were inclined at 45° to the electrode normal. The ratio R of the fission cross section at 0° to that at 90° for various neutron energies produced at the large Los Alamos Van de Graaff generator is given in Table I; earlier measurements with thermal and 14.3-Mev neutrons are included. At 7.5 Mev relative fission cross sections were measured at 0°, 15°, 30°, 60°, and 90°. The distribution satisfies $\sigma_f(\theta)\sim[1+0.07\times\cos^2\theta+0.29\cos^4\theta]$.

TABLE I.

E_n (Mev)	0	2.5	4.6	7.5	14.3	20.4
R	0.99 ± 0.05	1.02 ± 0.05	1.13 ± 0.06	1.36 ± 0.05	1.27 ± 0.08	1.11 ± 0.09

[1] W. C. Dickenson and J. E. Brolley, Jr., Phys. Rev. **90**, 388 (1953).

SATURDAY MORNING AT 9:30

NBS, East Building

(R. M. BOZORTH presiding)

Magnetism

T1. A Generator of Linearly Varying Current for an Electromagnet.* JOHN LEVINSON, *Alfred University.*—An all-electronic generator suitable for an electromagnet of 10 to 100 ohms resistance has been constructed and used in experiments on the magnetization of ferrites. Combined with automatic recording equipment, it has eliminated the need for manual setting of field values and the subsequent plotting of the dependent variables against the field. The current varies with time between adjustable limits up to plus or minus three amperes, the positive and negative limits not being necessarily equal. Characteristics desired were: (a) smoothness of variation, (b) high order of linearity in passing through zero current, and (c) cycling frequencies of 1, 3, and 10 cycles per minute, variable by about 50 percent. Circuit diagrams are presented showing how these characteristics were incorporated in the generator.

* Supported by the U. S. Office of Naval Research.

T2. Statistics of a Face-Centered Cubic Ferromagnet. E. DEMPSEY AND D. TER HAAR,* *St. Andrews University.*—

The variational method of Kramers and Wannier[1] for evaluating the partition function of the two-dimensional Ising model of a ferromagnet is extended to include next nearest as well as nearest neighbor interactions for a simple cubic ferromagnet.[2] Putting the interaction between nearest neighbors equal to zero leads to the equations for the Ising model of a face-centered cubic lattice involving nearest neighbor interactions only. These equations are solved by series expansions both for temperatures above and below the Curie temperature and series expansions for the partition function, configurational energy and configurational specific heat are obtained.

* On leave of absence at Purdue University.
[1] H. A. Kramers and G. H. Wannier, Phys. Rev. **60**, 252 (1941).
[2] Compare B. Martin and D. ter Haar, Physica **18**, 569 (1952).

T3. A Method of Measuring the Magnetic Properties of Ferromagnetic Materials by Means of the Hall Effect.* SIMON FONER,† *Carnegie Institute of Technology.*—The method described here is based on the assumption of the empirical formulation of the Hall effect in ferromagnetics, $e_H = R_0 H + R_1 M$, where e_H is the Hall electric field per unit current density, H is the magnetizing field, R_0 and R_1 are two constants of the material investigated and M is the magnetization. Measurements of e_H as a function of magnetic induction B may be used to determine R_0 and R_1. These constants are then used to calculate M as a function of B and therefore H. Since R_1 may be quite large for some materials, the changes in M may be greatly magnified. The method is independent of the demagnetizing factor and can be used to examine the magnetic hardness or domain size effect (a/H terms) in detail since any linear variation of M with H is absorbed by the R_0 term. The data for Armco iron at room temperature,[1] has been examined in detail. Any H dependent part of $\partial 4\pi M/\partial H$ as large as one gauss per oersted can be detected. The results generally agree with previous data obtained by other methods.

* Supported by the U. S. Office of Naval Research.
† Now at the Lincoln Laboratory.
[1] S. Foner and E. M. Pugh, Phys. Rev. **91**, 20 (1953).

T4. Magnetic Domains in Cobalt by the Longitudinal Kerr Effect.* CHARLES A. FOWLER, JR., AND EDWARD M. FRYER, *Pomona College.*—The Kerr magneto-optic effect has been successfully employed to photograph the antiparallel domains lying in those surfaces of a single cobalt crystal that contain the c axis, which is the direction of easy magnetization. The technique has been modified only slightly from that used by the authors in photographing the much larger domains of a silicon iron specimen.[1] Changes of the surface domain configuration as the crystal is carried from the demagnetized state to saturation can be observed. The saturated character of individual domains in the demagnetized specimen is demonstrated by a photoelectric record of local Kerr rotations. The photographic technique of negative-positive superposition, developed to improve the sharpness of the silicon iron photographs by reducing background, is essential in photographing the smaller cobalt domains. Other difficulties that attend the higher magnification are discussed.

* Supported by the U. S. Office of Naval Research.
[1] Fowler and Fryer, Revs. Modern Phys. **25**, 33 (1953); Phys. Rev. (to be published).

T5. Ferrimagnetic Resonance in Sintered Masses. DAVID PARK, *Williams College.**—Three factors must be considered in making a theory of this process in the absence of any steady external field. There are many crystallites, oriented at random; the crystallites will have different characteristic resonant frequencies, and they will interact with their neighbors. In order to approximate to a solution, we assume that the behavior of the group of neighbors of any crystallite X approximates that of the whole sample, and then find what this behavior must be in order that, at the same time, it be average over all X. Formulas for μ' and μ'' are then determined by what statistical distribution is assumed to characterize the resonant properties of the various crystallites. The results show most of the features of the observed data. Details will be given in the following talk.

* Work supported by the Sprague Electric Company.

T6. Domain Rotation in Sintered Nickel Ferrite. FIELDING BROWN AND CHARLES L. GRAVEL, *Sprague Electric Company.*—The complex permeability spectrum of sintered nickel ferrite has been measured between 2 mc and 3000 mc, and its dependence on maximum sintering temperature has been observed. Samples were prepared by pressing together fully reacted particles of nickel ferrite and sintering to various temperatures in the range 960–1350°C. The unsintered powder-wax samples show an absorption maximum at 2000 mc, in rough agreement with the theory of ferrimagnetic resonance,[1] and which moves smoothly to lower frequencies as the material is sintered to higher temperatures. The susceptibility at low frequency, x_0, is found to be inversely proportional to the frequency at which susceptibility is reduced to one-half this value, ω_0, in agreement with the theory of Snoek[2] for domain rotations. Since domain wall resonance predicts a different relationship ($(x_0)^{\frac{1}{2}}\alpha\omega_0^{-1}$) and since the crystallite size is very small in our samples, thus restricting possible domain wall relaxation to frequencies much higher than ω_0, the dispersion mechanism has been identified with domain rotation in an effective anisotropy field.

[1] F. Brown and D. Park, Phys. Rev. **93**, 381 (1954).
[2] J. L. Snoek, Philips Tech. Rev. **8**, 353 (1946).

T7. The Calculation of Ferromagnetic and Antiferromagnetic Curie Temperatures. H. A. BROWN AND J. M. LUTTINGER, *University of Michigan.**—Two well-known methods, both based on a Heitler-London approximation, have been used by Weiss[1] and Opechowski[2] to calculate Curie temperatures for spin $\frac{1}{2}$. Both methods have now been extended to higher spin. The Opechowski method requires only the calculation of traces of products of spin matrices as functions of the spin quantum number. The Weiss method is slightly modified in that, instead of finding the energy levels of the cluster exactly and then expanding the partition function in powers of the internal and applied fields, one obtains the series expansion directly by utilizing the fact that the partition function is a trace. The technique is equivalent to using perturbation theory and allows one to bypass the problem of diagonalizing a $(2S+1)$ by $(2S+1)$ matrix. The ferromagnetic Curie temperatures found by the Weiss method approach those of the third Opechowski approximation for high spin. An approximate model, in which spins are considered as classical vectors, has also been used in both methods and equivalent results found for high spin. Work is proceeding on the fourth and fifth Opechowski approximations.

* Work supported in part by the Wisconsin Alumni Research Foundation.
[1] P. R. Weiss, Phys. Rev. **74**, 1493 (1948).
[2] W. Opechowski, Physica **4**, 181 (1937); V. Zehler, Z. Naturforsch. **5a**, 344 (1950).

T8. The Spherical Model of an Antiferromagnet.* B. S. GOURARY AND R. W. HART, *The John Hopkins University.*—The sphericalization technique is adapted to the calculation of the partition function of a body centered cubic lattice of spins with isotropic antiferromagnetic interaction between nearest and second nearest neighbors. Two transition points are obtained. The usual Curie point transition from the paramagnetic state to the antiferromagnetic state (caused by the sticking of the saddle point) leads to an antiferromagnetic state with ordering either of the first kind or of the second kind,[1] depending on the value of the ratio of the second nearest neighbor interaction to the nearest neighbor interac-

tion. In addition, a transition from one kind of ordering to the other can occur if the ratio of the interactions varies with the temperature. Mathematically, this transition occurs because the largest eigenvalue of the interaction matrix becomes degenerate at the temperature at which the ratio of the interactions attains a certain critical value. These results are in qualitative agreement with molecular field theory.[2]

* Work supported by the Bureau of Ordnance, U. S. Navy.
[1] J. H. Van Vleck, J. phys. radium **12**, 262 (1951).
[2] J. S. Smart, Phys. Rev. **90**, 55 (1953).

T9. Neutron-Magnetic Diffraction Studies of Lanthanum, Calcium Manganites. W. C. KOEHLER AND E. O. WOLLAN, *Oak Ridge National Laboratory.*—A study has been made of the magnetic structures of a series of perovskite type compounds varying in composition from (100 percent La) MnO_3 to (100 percent Ca) MnO_3. In the composition range from about (0.9 La, 0.1 Ca) to (0.5 La, 0.5 Ca) the compounds are ferromagnetic with Curie temperatures ranging from near room temperature downward, in agreement with the magnetic measurements of Jonker and Van Santen.[1] The neutron diffraction studies show a series of different antiferromagnetic structures for compositions outside the above mentioned range and a coexistence of ferro and antiferromagnetic structures in the 0.9 La to 0.5 La composition range. The antiferromagnetic structures can at least partially be accounted for on the basis of magnetic cells which involve doubling of the chemical cell (a) along one axis, (b) along two axes, and (c) along three axes. The details of the proposed magnetic cells, their interrelations and their relation to composition and to the valence states of the manganese ions will be discussed.

[1] G. H. Jonker and J. H. Van Santen, Physica **16**, 337 (1950).

T10. Magnetostrictive Effects in α-Fe_2O_3. H. M. A. URQUHART* AND J. E. GOLDMAN, *Carnegie Institute of Technology.*—In a previous communication[1] magnetostrictive effects in antiferromagnetic α-Fe_2O_3 near the anisotropy transition were reported. The linear dependence on applied magnetic field of the temperature at which these effects disappear suggested that the transition temperature may be field dependent. Recent neutron diffraction studies[2] did not show such a dependence. Extension of our measurements to include the angular dependence of the distortion together with independent data on the magnetization[3] have suggested an explanation of the observed phenomena in terms of the possible existence of antiferromagnetic domains. The spin system senses the magnetic field through the accompanying unbalanced spins (parasitic ferromagnetism) which above the transition appears to follow the applied magnetic field when both are in the (111) plane. One cannot, however, unambiguously ascertain whether the antiferromagnetic part follows the field or sets itself perpendicular thereto. Our measurements suggest that the crystalline anisotropy in the high-temperature orientation is very much smaller than in the low-temperature system in agreement with recent observations of Anderson *et al.*

* Now at University of Pittsburgh.
[1] H. Urquhart and J. E. Goldman, Phys. Rev. **91**, 435 (1953).
[2] Corliss, Hasting, and Goldman, Phys. Rev. **93**, 893 (1954).
[3] C. Guillaud, J. phys. radium **12**, 489 (1951).

T11. Lattice Parameters of the $FeFe_{(2-x)}Cr_xO_4$ Spinel System.* H. J. YEARIAN, J. M. KORTRIGHT, AND R. H. LANGENHEIM, *Purdue University.*—Spinels of the $FeFe_{(2-x)}Cr_xO_4$, $0 \leqslant x \leqslant 2$, system have been made by reduction of the corresponding sesquioxide solid solution at 1180°C, 1100°C, and 950°C and the lattice parameters determined at room temperature. The solutions of approximately stoichiometric composition have lattice parameters which vary with x in a nonlinear manner from 8.396 ± 0.002A at $x=0$ to 8.376 ± 0.002A at $x=2$. The four essentially linear segments comprising the total curve are interpreted as follows: from $x=0$ to $x=0.3$ the structure is completely inversed; from $x=1.28$ to $x=2.0$ it is completely normal; between these regions reversion from the inversed to the normal form occurs in two successive stages. Oxygen-rich spinels crystallized at 950°C show the same general variations of parameter but the region of complete inversion extends to approximately $x=0.6$.

* Supported by the U. S. Office of Naval Research and Project SQUID

SATURDAY MORNING AT 9:30

Sheraton Park, Caribar Room

(P. G. BERGMANN presiding)

Theoretical Physics, V: Field Theory and Interactions

U1. Properties of Bethe-Salpeter Wave Functions. G. C. WICK, *Carnegie Institute to Technology.*—The analytic character of the relativistic wave function of a two-body system[1] in a bound state as a function of the "relative time" variable, or of the Fourier conjugate variable p_0 can be inferred from the definition of the wave function[2] plus some simple stability requirements. The analytic continuation of the wave function to imaginary values of p_0 is possible, and allows one to throw some light on the eigenvalue problem. Variational methods will be discussed. An example of an exact solution with $E \neq 0$ will be exhibited.

[1] H. A. Bethe and E. E. Salpeter, Phys. Rev. **82**, 309 (1951); **84**, 1232 (1951); J. Schwinger, Proc. Natl. Acad. Sci. U. S. **37**, 452, 455 (1951).
[2] M. Gell-Mann and F. Low, Phys. Rev. **84**, 350 (1951).

U2. Solutions of a Bethe-Salpeter Equation. R. E. CUTKOSKY, *Carnegie Institute of Technology.*—The Bethe-Salpeter equation in the ladder approximation, for the case of two scalar particles of equal mass interacting through a massless scalar field, is studied with the methods previously discussed.[1] At zero energy the equation may be transformed by the method of Fock,[2] and the solutions given by the spherical harmonics on a five-dimensional sphere. At energies different from zero a complete set of solutions may be obtained by an integral representation method.[1] The degeneracy of the eigenvalues will be discussed.

[1] G. C. Wick, preceding Abstract.
[2] V. Fock, Z. Physik **98**, 145 (1935); M. Levy, Proc. Roy. Soc. (London) **A204**, 145 (1950).

U3. Classical Limit of Pseudoscalar Coupling. W. E. THIRRING, *Institute for Advanced Study.*—The pseudoscalar coupling is approximated by the Hamiltonian $H=U(\rho_3 M + \rho_1 g\phi)+H^{\text{mes}}$ where M=nucleon mass, ϕ=meson field, U=source density with radius a. ρ is treated as a classical vector obeying the appropriate equations of motion. The free

gyration of ρ is quenched by the asymmetrical form of the coupling. The gyration forced by an incident meson wave causes scattering and photoabsorption. For $(g^2/4\pi)\ll 1$ the cross sections for scattering (σ_s) and photoproduction (σ_r) at low energies coincide with the perturbation theoretical values. For $(g^2/4\pi)\gg 1\sigma_s$ is independent of g and of the order a^2. The ratio between σ_p and σ_s is c^2v/g^2 for all g. The agreement with experiment, therefore, is worse for large values of g. A connection between a and M, g is not obtained as there is no consistent renormalization of a one nucleon theory. The results for charge symmetrical coupling are similar. Although the connection between this calculation and the complete field theory is questionable, it may indicate that a possible suppression of σ_s at large values of g will suppress σ_p, too. This point seems to be a serious disagreement between pseudoscalar theory and experiment.

U4. On the Factorable Neutron-Proton Interaction. YORIKO YAMAGUCHI AND YOSHIO YAMAGUCHI, *University of Illinois.*—The two body Schrdöinger equation can be solved exactly for a factorable nuclear potential with momentum matrix elements of the form $(\mathbf{p}|V|\mathbf{p}')=\lambda g(\mathbf{p})g(\mathbf{p}')$. Simple examples for (*i*) ^1S-interaction, $g(\mathbf{p})=(\beta^2+p^2)^{-1}$, and (*ii*) eigen ^3S-interaction, $g(\mathbf{p}) = (\beta^2 + p^2)^{-1} - 8^{-\frac{1}{2}}\{(\boldsymbol{\sigma}^p\mathbf{p})(\boldsymbol{\sigma}^n\mathbf{p})p^{-2} - (\boldsymbol{\sigma}^p\boldsymbol{\sigma}^n)\}\times t\rho^2(\gamma^2+p^2)^{-2}$, have been investigated in detail. The deuteron D-state probability and quadrupole moment, and $k\cot\delta$ for $N-P$ scattering have been expressed in analytic forms and fitted by adjusting the parameters β, γ and t. The $N-P$ scattering up to 100 Mev can be fitted fairly well using (*i*) and (*ii*) alone. The photo-disintegration of the deuteron has also been analyzed with consideration of the gauge-invariance problem. The total cross section (E.D. plus M.D.) agrees with the observed data[1] up to photon energies of ~60 Mev, but the angular distribution has too small an isotropic component. The D-wave function of the deuteron becomes important with increasing photon energy. Consideration of thermal neutron capture by hydrogen confirms Austern's conclusion[2] that an interaction magnetic moment is needed.

[1] Allen, Hanson, and Whalin (private communication).
[2] N. Austern, Phys. Rev. **92**, 670 (1953).

U5. General Conditions on the Scattering Matrix. M. L. GOLDBERGER, *Princeton University*, M. L. GELLMAN, *University of Chicago*, AND W. E. THIRRING, *Institute for Advanced Study.*—Van Kampen[1] has discussed the limitations which may be imposed on the S matrix by certain causality requirements. His treatment has been reformulated in a simple and entirely quantum mechanical manner. Our method is readily generalizable to treat the problem of scattering of particles with rest mass. The fundamental idea is to demand that any expectation value of the commutator of two field operators must vanish for two points separated by a space-like interval. The special problem considered is a quantized field interacting with a given external field. The latter is supposed to be exactly zero outside a certain domain. The most powerful statements which are independent of the size of the region of interaction can be made for the forward scattering amplitude. They give a relation connecting the real part of the forward scattering amplitude and the total cross section. Sum rules of the familiar Kramers-Kronig form can be derived without reference to the scattering mechanism. Applications of these relations to scattering of γ rays by atoms, photonuclear reactives, scattering of photons by nucleons will be discussed. Generalizations of the results for the case of two coupled quantized fields are considered.

[1] Van Kampen, Phys. Rev. **89**, 1072 (1953).

U6. Nuclear Rotational Levels and the μ-Mesic Atom. B. A. JACOBSOHN, *University of Washington.*—Nuclei which, according to the Bohr-Mottelson collective model,[1] possess low-lying rotational excitations can be excited with relative ease by the electric field of a μ meson in an inner Bohr orbit. Since the energy differences between different μ states are large, the meson can be considered to be in a single orbit. However for heavy nuclei which are far removed from closed-shell configurations, the nuclear levels are closely spaced and are connected by large quadrupole matrix elements. The coupled system is one in which the stationary states correspond to the μ in a single orbit and the nucleus existing in mixtures of several states. The lifetimes of these states are determined by the meson transitions. Calculations of the effect on the $2p\rightarrow 1s$ line have been carried out using the collective model.[1] The result is that this line is split into several components with a shifted center of gravity. In favorable cases, the splitting may be as much as several hundred kilovolts. The effect can probably be ignored in those cases which have been investigated experimentally up to the present.[2]

[1] A. Bohr and B. R. Mottelson, Kgl. Danske Videnskab. Selskab Mat.-fys. Medd. **27**, No. 16 (1953).
[2] V. L. Fitch and J. Rainwater, Phys. Rev. **92**, 789 (1953).

U7. Red-shifts in the Spectra of Celestial Bodies. E. FINLAY-FREUNDLICH, *University Observatory, St. Andrews, Scotland* (introduced by D. ter Haar).—It is shown that red-shifts occurring in the spectra of B- and O-stars are too large to be gravitational red-shifts such as are predicted by the theory of relativity. It is suggested that the red-shifts may be due to a loss of energy in the radiation field of the stars. If $\Delta\nu/\nu$ is the fractional change of frequency of the lines, T the temperature of the radiation field, l the length of path traversed through the radiation field, the following relation holds: $\Delta\nu/\nu=-AT^4l(A)$, where A is a constant. It is shown that formula (A) can account for red-shifts observed in the spectra of O, B, A, supergiant M, W-R stars and of the sun. In addition to the red-shift given by formula (A) the data from the sun and from Sirius B (a white dwarf) seem to suggest that there exists an additional gravitational red-shift which is, however, only a fraction (about one-fifth) of the red-shift predicted by the theory of relativity.

U8. Classical Radiation from Moving Charges. SIDNEY A. BLUDMAN, *University of California, Berkeley.*—For an arbitrarily moving charged particle, a coordinate system can be introduced in which the particle remains permanently at rest and the spatial axes are not rotated. Maxwell's equations can be solved in these curvilinear coordinates: the field is coulombic and the Poynting flux vanishes so that, by this coordinate transformation, the radiation field has been transformed away. The equations of motion for particles reveal, of course, the non-inertial character of this coordinate system. On transforming back to an inertial system, the conventional formula for the field of an arbitrarily moving charge is obtained. The radiation damping force is shown to transform as a vector under conformal transformations so that it vanishes only for the uniformly accelerated motions generated from rest by the conformal group. In linear accelerators this uniform acceleration obtains and the small amount of energy radiated is due entirely to changes in the acceleration energy of the particle. This work was performed under the auspices of the U. S. Atomic Energy Commission.

U9. Dyson's New Tamm-Dancoff Method. ABRAHAM KLEIN,* *Harvard University.*—The three-dimensional formalism proposed by Dyson,[1] though attractive in many respects, poses several questions that remain to be clarified. Since the method employs covariant amplitudes with all times set equal, one might expect to find a simple relationship between the equations obtained from a covariant treatment and Dyson's equations, after the elimination of higher amplitudes. For the one-particle problem, a three-dimensional equation for a stationary state can be deduced from the

covariant one without approximation and compared with the new T.-D. equation, since simple rules can be given for constructing the latter to any approximation. The kernels agree only to lowest order, which explains the renormalizability of Dyson's equation in that order, but casts doubt upon the renormalizability of the equation as a whole by available methods. Similar remarks obtain for the two-particle problem. Further, the simple example of a two-component spinor field interacting with a boson field—the true and free vacuum states are then equal—provides evidence against the validity of Dyson's rule for prescribing that the comparison state for all energies is the vacuum state.

* Society of Fellows.
[1] F. J. Dyson, Phys. Rev. **91**, 1543 (1953).

U10. Exchange Current Effects in the Deuteron. J. BERNSTEIN AND A. KLEIN,* *Harvard University.*—Recent treatments by Villars[1] and Deser[2] of corrections to the quadrupole moment of the deuteron arising from nucleon recoil upon emission of a meson has led to values of 10 percent and more. Though one might expect *a priori* that one is dealing with a dynamic effect which vanishes when nucleon recoil is neglected in intermediate states (as found by Villars), the effective current operator found by Deser does not show this behavior. Since this discrepancy arises from the difference in treatment, we have reexamined the problem by all available methods: (a) canonical transformation, (b) Tamm-Dancoff method, (c) covariant two-nucleon equation. Methods (b), and (c) indicate an ambiguity which is the analogue of that arising in the problem of computing fourth order nuclear forces from gradient coupling, and results of the character of those found by both previous authors can be obtained under suitable approximations. Formulas and results will be presented and discussed.

* Society of Fellows.
[1] F. Villars, Phys. Rev. **86**, 476 (1952).
[2] S. Deser, Phys. Rev. **92**, 1452 (1953).

U11. Two-Body Forces and Nuclear Saturation. I. Method. K. BRUECKNER, C. LEVINSON, AND H. MAHMOUD, *Indiana University.**—The investigation of nuclear saturation for potentials for which Born approximation is valid is a relatively simple problem. For the rapidly varying and nonmonotonic potentials of pseudoscalar meson theory, however, variational methods using independent particle trial functions are grossly inadequate. The problem can be approached using more general variational functions with interparticle correlation; the evaluation of the resulting expressions is very difficult since indirect correlations involving many more than two particles become important at high densities. An alternative procedure has been developed which allows a rather straightforward evaluation of the many-body energy even when the potentials are of great complexity. This method depends on an approximation, valid in the limit of very many scatterers, which leads to an exact solution (a degenerate Fermi gas) for the coherent particle motion. In this case the many body potential energy can be simply expressed in terms of the low energy scattering amplitudes so that details of the two-body potential configuration are unimportant. The method also allows evaluation of correction terms arising from incoherent contributions to the particle motion. These corrections indicate the extent to which the coherent wave motion differs from an independent particle motion.

* Supported in part by the National Science Foundation and the Joint Program of the U. S. Office of Naval Research and the U. S. Atomic Energy Commission.

U12. Two-Body Forces and Nuclear Saturation. II. Results. C. LEVINSON, K. BRUECKNER, AND H. MAHMOUD, *Indiana University.**—The method described in the previous abstract has been applied to the two-body potentials given by pseudoscalar meson theory when the effects of nucleon pair formation are assumed to be small. In this approximation the many body forces of the theory are negligible. These potentials give an excellent fit to the low energy scattering parameters of the two-nucleon system and also an approximately correct description of scattering up to 90 Mev. They are characterized by repulsive cores of radii 0.3–$0.4\hbar/\mu c$ and quite weak interactions in odd states. The many body energy has been evaluated neglecting the tensor contributions which average to zero in first approximation. The result shows saturation at an energy per particle (neglecting Coulomb energy) of 12 Mev at a nuclear radius $1.15\times10^{-13}A^{\frac{1}{3}}$ cm. The position and magnitude of the saturation minimum in the energy are rather sensitive to the repulsive cores in P states which were taken to be $0.4\hbar/\mu c$ for the above result. The repulsive forces which lead to the saturation arise principally from the effect of the repulsive cores on the S-wave scattering, the phase shifts changing sign at high energy. The method has also been applied to potentials of the Levy type in which the odd-state potentials are rather strong and attractive.

* Supported in part by the National Science Foundation and the Joint Program of the U. S. Office of Naval Research and the U. S. Atomic Energy Commission.

SATURDAY AFTERNOON AT 1:30

Sheraton Park, Caribar Room

(E. P. WIGNER presiding)

Theoretical Physics, VI: Atoms and Electrons

V1. Electronic Polarizabilities of Ions from the Hartree-Fock Wave Functions.* R. M. STERNHEIMER, *Brookhaven National Laboratory.*—The electronic polarizability α can be written as a sum of terms of the type $a\int_0^\infty u_0 u_1 dr$, where a = coefficient, u_0 and u_1 are r times the radial part of the unperturbed wave function and the perturbation, respectively, for a particular shell and excitation. α has been calculated for 14 ions using the Hartree-Fock wave functions for u_0. For the He-like ions, an analytic expression for u_1 can be obtained, if the $1s$ wave functions of Löwdin[1] are used. For the heavier ions, the differential equations for the u_1 were solved numerically. The most important term of α arises from the excitation of $nl\rightarrow l+1$, were n and l are the principal and azimuthal quantum number of the highest filled subshell. The calculated values of α for most cases lie between 1 and 1.5 times the experimental values. Values have also been obtained for the quadrupole polarizability which measures the quadrupole moment induced in the ion by the field of an external charge.

* Work done under the auspices of the U. S. Atomic Energy Commission.
[1] P. O. Löwdin, Phys. Rev. **90**, 120 (1953).

V2. A Perturbation Calculation of Elastic Exchange Scattering of Electrons by Hydrogen Atoms.* SIDNEY BOROWITZ, *New York University.*—We consider the elastic exchange scattering of electrons by hydrogen atoms. If the mass of the proton is considered infinite, one can take as a perturbation either the interaction of the electron with both particles of the scatterer (asymmetric perturbation), or merely the interaction between the two electrons (symmetric perturbation). We have treated the latter case to first order. This method leads to integrals which can be evaluated exactly, after suppressing terms which seem to arise from the logarithmic phase factors in the asymptotic behavior of unscreened Coulomb wave functions. The results indicate that the symmetric perturbation calculation gives a completely different energy dependence for the exchange scattered amplitude than does the asymmetric perturbation calculation.[1]

* Research supported by contract with Air Force Cambridge Research Center Air Research and Development Command.
[1] Corinaldesi and Trainor, Nuovo cimento **9**, 1952.

V3. An Approximate Correlation Potential. JOSEPH CALLAWAY, *Princeton University.*—The success of Slater's free electron approximation to the exchange potential[1] suggests a similar approach to the correlation energy. Wigner's formula for the correlation energy of a free electron gas[2] is to be modified by making the density of electrons a function of position, and gives as a correlation potential to be added to Hartree or Hartree-Fock equations (for electrons of positive spin):

$$V(r)=\frac{0.576e^2}{(3/8\pi\rho(r))^{\frac{1}{3}}+5.1}.$$

Here ρ_- is the local density of electrons of negative spin. Applications of this formula to ferromagnetism are in progress. For iron at the observed lattice spacing, this formula indicates correlation effects are too small compared to the exchange potential to alter the predictions of the energy band theory of ferromagnetism.

* National Science Foundation Predoctoral Fellow.
[1] J. C. Slater, Phys. Rev. **81**, 385 (1951).
[2] E. P. Wigner, Phys. Rev. **46**, 1002 (1934).

V4. SCF Treatment of Unclosed Shells, Operators Containing Spin, and Radial Correlation. PAUL F. WACKER, *Catholic University of America.*—In computing the energy of states belonging to degenerate spin-space symmetry species, configurations or combinations of configurations belonging to all but one subspecies may be disregarded. Hence, a single determinant may often be used. The energy is then given[1] by $tr(\mathbf{H}+\frac{1}{2}tr_{2,4}(\mathbf{j}-\mathbf{j}^{\dagger_{2,4}})\boldsymbol{\rho})\boldsymbol{\rho}$. The ith spin-orbital eigenvector $\mathbf{Ci}$ of a Hartree-Fock treatment[2] is a solution of $\mathbf{FCi}=f_i\mathbf{SCi}$, where $\mathbf{F}=\frac{1}{2}\mathbf{H}+\frac{1}{2}tr_{2,4}(\mathbf{j}-\mathbf{j}^{\dagger_{2,4}})\boldsymbol{\rho}$, f_i is an eigenvalue, and $\mathbf{S}$ is the spin-orbital overlap matrix. If the Hamiltonian contains spin, these equations automatically include a perturbation treatment of the spin effects. If Russell-Saunders coupling occurs, α or β spin may be assigned to each spin orbital, simplifying the equations. The nonzero halves of the eigenvectors are then given by $\mathbf{F}_{\alpha\alpha}\mathbf{C}_{i\alpha}=f_i\mathbf{S}\mathbf{C}_{i\alpha}$ and $\mathbf{F}_{\beta\beta}\mathbf{C}_{i\beta}=f_i\mathbf{S}\mathbf{C}_{i\beta}$, where S is the overlap matrix for spatial orbitals, while $\mathbf{F}_{\alpha\alpha}$ and $\mathbf{F}_{\beta\beta}$ are diagonal quadrants of the $\mathbf{F}$ matrix. Since a different spatial orbital is assigned to each electron, these equations treat "radial" correlation. If correlation is neglected, further simplification results.

[1] Wacker, Phys. Rev. **91**, 465A, 429 (1953).
[2] Roothaan, Revs. Modern Phys. **23**, 69 (1951).

V5. Coulomb Wave Functions for Large Values of the Parameter n. L. C. BIEDENHARN, R. L. GLUCKSTERN, AND M. H. HULL, JR., *Yale University.**—Current interest in nuclear reactions involving heavy charged particles and in Coulomb excitation of nuclei has pointed up the need for Coulomb wave functions for large values of the parameter $\eta=ZZ'e^2/(\hbar v)$. The Coulomb functions commonly denoted[1] by $F_L(\rho)$, $G_L(\rho)$, as well as their derivatives $F_L'(\rho)$, $G_L'(\rho)$, have been represented, therefore, by power series expansions in $\hbar^{-1}$ at the classical turning point $\rho_L=\eta+[\eta^2+L(L+1)]^{\frac{1}{2}}$ and at $\rho_0=2\eta$ somewhat as in earlier work of others[2] primarily at $L=0$. The usefulness of this type of expansion is apparent from the fact that one or two terms suffice to reproduce numerical results[3] for $L=0$ at ρ_0 with $10\leq\eta\leq200$, as has been pointed out by Newton.[2] Expansions applicable for large L at $\rho=\rho_0$ have also been obtained. In addition, approximate wave functions for arbitrary values of ρ in the vicinity of ρ_L will be presented.

* Assisted by the Office of Ordnance Research, U. S. Army and by the joint program of the U. S. Office of Naval Research and the U. S. Atomic Energy Commission.
[1] Yost, Wheeler, and Breit, Phys. Rev. **49**, 174 (1936).
[2] J. K. Tyson, thesis, MIT, (1948); T. D. Newton, Chalk River Project report CRT-526 (1952); Feshbach, Shapiro, and Weisskopf, NYO-3077 (1953).
[3] W. D. Barfield and A. A. Broyles, Phys. Rev. **88**, 892 (1952).

V6. (Abstract withdrawn.)

V7. W.K.B. Approximation through the Turning Point. A. A. BROYLES, *The Rand Corporation.*—The W.K.B. approximation is quite useful for many wave functions at some distance from the classical turning point. The infinity at the turning point may be removed without serious damage to the approximation at other points by multiplying the energy or the potential by a constant S near unity. This constant is determined on each side of the turning point so that the resulting approximation and its derivatives match at the turning point. The method was tried on hydrogen bound wave functions for the outside turning point using a normalization integral equal to

$$\frac{1}{2}\int_{R_1}^{R_2}\frac{1}{(\epsilon-U)^{\frac{1}{2}}}dR$$

where R_1 and R_2 are the turning points. This is equivalent to replacing the cosine squared by $\frac{1}{2}$. Inside the turning point, the energy ϵ was multiplied by S_i and outside, the potential, U, was multiplied by S_0. The phase $-\pi/4$ was replaced by

$$\phi=-(\pi/4)+(n-l+\tfrac{1}{2})\pi-\int_{R_1}^{R_2}(S_i\epsilon-U)^{\frac{1}{2}}dR.$$

V8. Calculation of Potential from the Transit Time.* JERRY SHMOYS AND SAMUEL N. KARP, *New York University.*—The potential is calculated from the transit time of a particle crossing a potential well. The particle is assumed to move according to the classical laws of motion. Similarly, the charge density of the ionosphere could be calculated from the transit time of a radio pulse through a series of ionospheric layers; to do this one would have to assume that the pulse moves with the group velocity of the medium, and that the medium is lossless. The potential thus calculated is not unique but this deficiency turns out not to be too serious. The method involves the use of the Mellin transform of the transit time with respect to energy (or frequency). Some quantities characterizing the well can be obtained from the Mellin trans-

form directly, i.e., without calculating the inverse transform. The procedure is illustrated by the case of an exponential well.

* This work was performed at the Institute of Mathematical Sciences, New York University and was supported in part by the U. S. Air Force, Air Force Cambridge Research Center, Air Research and Development Command.

V9. A Simplifying Approximation for Determining Cascade Shower Distributions. BAYARD RANKIN, *University of California, Berkeley, California.*—The state of an electron-photon shower at depth x is specified (ignoring lateral spread) by the parameters $(I, \epsilon, N, \mathbf{E}, \lambda)$ representing, respectively, the initial energy, the energy below which particles are not observed, the number of particles, an N-dimensional energy vector, and the ordering of electrons and photons among the energy components of $\mathbf{E}$. The ordering parameter λ will have 2^N permissible values. It is possible to solve directly for the probability $P(N, \Delta\mathbf{E}, \lambda)$ of the set of states with energies contained in $\Delta\mathbf{E}=(\mathbf{E}, \mathbf{E}+\epsilon\mathbf{1})$. One solves simultaneously for all probabilities, $P(N, \Delta\mathbf{E}, \lambda)$, with common $(N, \Delta\mathbf{E})$ and different λ and uses recurrence relations for probabilities with different $(N, \Delta\mathbf{E})$. This has been done assuming energy-dependent bremsstrahlung, materialization, collision loss, and multiple scattering, and assuming ϵ/I is small. (UCRL Report 2322.) Unfortunately, the simultaneous set of $P(N, \Delta\mathbf{E}, \lambda)$ for fixed $(N, \Delta\mathbf{E})$ may be large. To limit the number of unknowns, one can choose for $x \to 0$ an ordering parametrization (different for different $(N, \Delta\mathbf{E})$) such that $P(N, \Delta\mathbf{E}, \lambda)$ is smooth (or quadratic) as a function of λ. Once this smoothness is established, it should persist as x increases. Now for each $(N, \Delta\mathbf{E})$ only the three x-dependent coefficients in the quadratic function are unknown and the solution is expressible in 3×3 matrices.

V10. Pair Production and Bremsstrahlung in the Field of an Electron. F. ROHRLICH, *State University of Iowa.*—The exact differential cross section for pair production by gamma rays in the field of an electron is obtained. The calculation neglects neither recoil nor exchange effects and does not assume the initial electron to be at rest. Therefore, the result gives also the differential cross section for bremsstrahlung in electron-electron collisions (for equal signs of the charges), provided suitable signs are changed and a different density of final states is employed. The integration of these cross sections will be discussed. The results can be compared with previous exact calculations by Votruba[1] and approximate calculations by Borsellino[2] who neglects exchange. The final formulas given by Borsellino are incorrect.

[1] V. Votruba, Bull. intern. acad. tcheque sci. **49**, 19 (1948); Phys. Rev. **73**, 1468 (1948).
[2] A. Borsellino, Nuovo cimento **4**, 112 (1947).

V11. Theoretical Energy and Angular Distributions of Bremsstrahlung Electrons.* PHILIP T. MCCORMICK,† *University of Notre Dame.*—The Bethe-Heitler triple differential bremsstrahlung cross section[1] has been integrated over the angles of the radiated photon to obtain the distribution in energy and angle of the scattered electron. The calculation has been carried out exactly using a pure Coulomb field and preliminary numerical results for the electron energy-angle distributions have been obtained for incident electrons of kinetic energies corresponding to momenta of 2 mc, 4 mc, 6 mc, 10 mc, and 20 mc scattered at angles of 30°, 60°, 90°, 120°, and 150° with the direction of the incident electrons. Because the calculation was lengthy, further checks on it are being planned in order to assure the correctness of the results.

* This work was submitted by Philip T. McCormick in partial fulfillment of the requirements for the Ph.D. degree at the University of Notre Dame.
† Now at DePaul University, Chicago, Illinois.
[1] W. Heitler, *The Quantum Theory of Radiation* (Oxford University Press, London, 1949), second edition, p. 164.

V12. Interference Effects in the Annihilation Process.* G. GIBSON AND P. STEHLE, *University of Pittsburgh.*—The two-photon annihilation process has been considered in the limit of small velocities for a positron incident on a localized two-electron system. We have treated the situation where one electron annihilates with the positron, while the state of the second electron is altered by the removal of the first. If the electrons are initially in a singlet state, then the absolute square of the transition amplitude is of order β^2 for the triplet annihilating state, and of order $1+\beta^2$ for the singlet annihilating state. However, these are two processes not leading to the same final state for the surviving electron. In order to have interference it is necessary that neither of the initial electron states be orthogonal to the final electron state, and that the Fourier transforms of both electron states are finite for the momentum required of the annihilating electron by the conservation laws. If the electrons are initially in a triplet state, they have symmetric roles in the annihilation, and interference effects may result from electron exchange. This effect is being investigated for annihilation in multielectron atoms.

* Work done at the Sarah Mellon Scaife Radiation Laboratory and assisted by the Joint Program of the U. S. Office of Naval Research and the U. S. Atomic Energy Commission.

V13. Electromagnetic Scattering by Dielectric Bodies.* MARSHALL H. COHEN, *The Ohio State University.*—The field scattered by a dielectric body may be approximated by using Rumsey's "reaction method"[1] and volume polarization currents. This method gives a phase and amplitude for the assumed current, with respect to the incident field, and leads directly to the variational equations used by Lurye.[2] Calculations for the echo width of a lossless circular cylinder have been made and compared with the exact solution. The cylinder is one free-space wavelength in diameter and a plane wave is incident normally on it. There are three major conclusions. It is important to have a good current assumption because different ones give substantially different results. The current $Ae^{-ik_1x}+Be^{ik_1x}$, where k_1 is the propagation constant of the medium and A and B are determined by the reaction equations, gives very good results over the first resonance region. The reaction method gives better results than the classical iterated integral equation solution,[3] for the same amount of labor.

This work was done under a contract between Wright Air Development Center and the Ohio State University Research Foundation.
[1] V. H. Rumsey, "The reaction concept in electromagnetic theory," Phys. Rev. (to be published).
[2] J. R. Lurye, "Electromagnetic Scattering Matrices of Stratified Anisotropic Media," Report EM-11, Mathematics Research Group, New York University.
[3] D. R. Rhodes, "On the Theory of Scattering by Dielectric Bodies," Report 475-1 Antenna Laboratory, Ohio State University.

V14. High-Speed Computation of Angular Momentum Functions. ALBERT SIMON, *Oak Ridge National Laboratory.*—The Racah function $W(abcd; ef)$[1] has proven to be an invaluable tool in the general treatment of angular distributions of nuclear reactions, angular correlation, etc. A complete table of the numerical values of this function, up to the limits $a, c \leq 15/2$; $b, d \leq 9/2$; $e \leq 3$; $f \leq 8$, has been obtained by a UNIVAC calculation and will be published shortly. Some general aspects of the method of computation and the form of presentation will be discussed. The circumstance that a partial table of these functions was computed earlier[2] by the use of desk machines permits an illuminating comparison of labor involved. An entirely similar routine is needed for the computation of the Clebsch-Gordan coefficients. Such a table has been prepared with the restriction that none of the arguments be larger than 9/2. Extension of these tables to higher limits would be trivial and will be done if a sufficient demand exists. The X^3 and G functions[4] are needed for the more general problems of polarization in nuclear reactions, radiation from aligned nuclei, etc.

[1] G. Racah, Phys. Rev. **62**, 438 (1942).
[2] L. C. Biedenharn, U. S. Office of Naval Research Laboratory Report 1098.
[3] U. Fano, U. S. National Bureau of Standards Report 1214; A. Simon and T. A. Welton, Phys. Rev. **90**, 1036 (1953).
[4] A. Simon, Phys. Rev. **92**, 1050 (1953).

SATURDAY AFTERNOON AT 1:30

Sheraton Park, Burgundy Room

(J. O. HIRSCHFELDER presiding)

Fluid Dynamics

Invited Papers

VA1. Theory of Turbulent Diffusion. F. N. FRENKIEL, *Applied Physics Laboratory, Johns Hopkins University.* (30 min.)

VA2. On the Interaction of Shock Waves. OTTO LAPORTE, *University of Michigan.* (30 min.)

Contributed Papers

VA3. Ideal Flow and Creeping Motion. K. M. SIEGEL AND A. H. HALPIN, *University of Michigan,* AND A. L. MAFFETT, *Gettysburg College.*—It is shown that any ideal fluid stream-function when multiplied by a radial distance squared yields a nontrivial solution to the equation of creeping motion. Similarly this creeping motion solution can be used to find a new ideal fluid solution. This scheme shows that we can find expansions which do not depend on the separability of the original partial differential equation. All presently known solutions of creeping-motion boundary-value problems can be obtained in this manner.

VA4. A Spatial Spectrum for Turbulent Shear Flow. WILLEM V. R. MALKUS, *Woods Hole Oceanographic Institution.*—A statistical mechanical criterion for steady-state fluid dynamics has yielded the approximate principle that the turbulent motion in shearing flow maximizes the rate of dissipation. This principle is applied to determine the spatial spectrum of momentum transport in channel flow, subject to the stability constraint that an arbitrary smallest scale of motion contributes to this transport. The predicted spectrum leads to a "velocity defect law," a "logarithmic velocity law," and an analytic description of the "boundary layer," not as separate deductions, but as a single expression from one solid boundary to the other. This theory has one parameter, the minimum eddy size. That relation between minimum eddy size and Reynolds number which gives best agreement with the observations is determined.

VA5. Numerical Solution of a Spherical Blast Wave. HAROLD L. BRODE, *The Rand Corporation.*—The strong shock, point source, similarity solution[1] was used as initial conditions in a numberical integration of the differential equations of gas motion in Lagrangian form. The technique of Von Neumann and Richtmyer[2] which introduces an artificial viscosity was employed. The solutions were carried from two thousand atmospheres down to one tenth atmospheres peak overpressure. Results include pressure, density, particle velocity, and position as functions of time over a graduated space grid of ninety divisions. The problem was coded for both the ORDVAC and the IBM-701 high speed computers, and was repeated both with an ideal gas assumption and with a more detailed equation of state. A study was made of the effects of such factors as the shock width, the initial shock strength, the space and time grid sizes, the sphericity, the stability, the loss of significance and some other features of the numerical computation.

[1] J. Von Neumann, AECD-2860, "Shock Hydrodynamics and Blast Waves," Los Alamos Scientific Laboratory, October 28, 1944.
[2] J. Von Neumann and R. D. Richtmyer, J. Appl. Phys. **21**, 232 (1950).

VA6. General Relations in a Fluid Convection Theory. II. Conditions for Flow-Patterns. F. T. ROGERS, JR., *University of South Carolina.*—Attention has been called[1] to the role of repetitive flow-patterns (whether cellular or columnar) in the problem of the onset of convection in a fluid in a porous medium and heated from below. Reference 2 summarizes the problem for a nonstatic thermal environment and temperature-dependent viscosity. It is found that if the basic differential equations for the thermodynamic-hydrodynamic interrelationship are approached (in the sense of least squares) through trigonometric series of finite length, a straightforward course is open for calculation of the dimensionless quantity, E^2D^2, which characterizes the repetitive flow pattern. Moreover a way is found for solution of the larger problem by the requirements of consistency. In even the one-term-series approximation it appears that if the flow-pattern is repetitive, then the flow-"cell" dimensions are in part dependent upon the temperature-dependence of viscosity.

[1] Paper read at the Oak Ridge meeting, April, 1954.
[2] F. T. Rogers, Jr., J. Appl. Phys. **24**, 877 (1953).

VA7. Upstream Effects Induced by a Jet Exhausting from the Base of a Body of Revolution. J. L. POTTER AND N. M. SHAPIRO, *Ordnance Missile Laboratories.*—An experimental investigation of the flow upstream of the base of a body of revolution in a subsonic stream with and without a jet exhausting from the base is described. From evidence furnished by surveys of pressure and velocity distribution in the flow, it is seen that a jet issuing from the base of a body induces acceleration of the fluid approaching the base, the magnitude of this effect varying with axial and radial distance from the jet exit as well as other theoretically predicted parameters. The significance of this phenomenon is demonstrated by its influence on the load distribution on stabilizing fins located near the base of a body.

SATURDAY AFTERNOON AT 1:30

Sheraton Park, Continental Room

(J. A. DE JUREN presiding)

Neutron Physics, III

W1. Cross Section for Producing High-Energy Neutrons from Carbon Targets Bombarded by Protons, Deuterons, and He^3 Particles.* L. SCHECTER AND W. E. CRANDALL, *California Research and Development Company,* AND G. P. MILLBURN AND J. ISE, *University of California, Berkeley.*—The differential cross section, $d\sigma/d\Omega$, for producing neutrons with energy in excess of 20 Mev from carbon targets bombarded by 340-Mev protons, 190-Mev deuterons, and 490-Mev He^3 particles were measured. The absolute cross sections were determined by counting identical carbon targets and neutron detector foils in the same geometry and utilizing the known excitation functions for the neutron and bombarding particles.

* Supported by the U. S. Atomic Energy Commission.

W2. Total Cross Sections for High-Energy Neutrons.* R. W. WANIEK AND VAUGHN CULLER, *Harvard University.*—A good geometry attenuation experiment for measuring the total nuclear cross sections of various elements has been performed with neutrons produced from a ¼-in. beryllium target bombarded by the 110-Mev internal proton beam of the Harvard 95-inch synchrocyclotron. The neutron beam collimated by pipes of rectangular cross section was first monitored by a triple coincidence scintillation counter telescope. Then the beam was attenuated by samples of various elements and the resultant intensity determined by another scintillation counter telescope. By the selection of three, four, five and six-fold coincidences energy bands of approximately 5-Mev absolute total width were defined. The effective energy spread is therefore considerably smaller. Cross sections of hydrogen, deuterium, carbon, oxygen, aluminum, silicon, iron, and lead have been measured and the results will be presented.

* Supported by the joint program of the U. S. Office of Naval Research and the U. S. Atomic Energy Commission.

W3. Photoneutron Cross Sections in He, N, O, F, Ne and A. G. A. FERGUSON, J. HALPERN, R. NATHANS, AND P. F. YERGIN, *University of Pennsylvania.*—The apparatus previously reported[1] for the direct detection of neutrons from (γ,n) reactions induced by betatron bremsstrahlung has been modified to permit cross section determinations using gaseous targets at 100 atmospheres pressure. Results from oxygen are consistent with other determinations.[2] The remaining elements, representing new results, show the familiar giant dipole resonance for the photoneutron process. Helium has a resonance peak at 24 Mev with a 4-Mev half-width, a peak cross section of 1.25 millibarns and an integrated cross section of 6 Mev-millibarns. The other elements show behaviors consistent with the systematics reported[3] for (γ,n) reactions. The lower the Z of the element, however, the greater is the difference between the observed integrated cross sections for $(\gamma,n)+(\gamma,p)+(\gamma,pn)$ reactions and the sum rules. An explanation of this result in terms of various models will be proposed.

[1] Halpern, Mann, and Nathans, Rev. Sci. Instr. **23**, 678 (1952).
[2] Montalbetti, Katz, and Goldemberg, Phys. Rev. **91**, 659 (1953).
[3] R. Nathans and J. Halpern, Phys. Rev. **92**, 207 (1953).

W4. Photoneutron Angular Distributions. K. GELLER, J. HALPERN, AND PAUL F. YERGIN, *University of Pennsylvania.*—The angular distributions of photoneutrons produced by 22 Mev bremsstrahlung on Pb, Ag, and Cu have been measured using a lucite-zinc sulfide fast neutron detector.[1] The results do not show any significant nonisotropy. If the distributions are fitted to the form $A+B\sin^2\theta$, the value of B/A consistent with the data for any of the elements could not exceed 0.12. If we make approximate estimates of the neutron energy distributions for two different models, the evaporation model and Courant's direct photoeffect model,[2] and if we assume that all of the nonisotropic component is the result of direct photoeffect, and take into account the measured energy sensitivity of the type of detector used,[3] then the cross section for direct photoeffect production of the nonisotropic component is not more than 1 percent of the total cross section for Cu, and must be considerably less for Ag and Pb, for which the data is better.

[1] W. F. Hornyak, Rev. Sci. Instr. **23**, 264 (1952).
[2] E. D. Courant, Phys. Rev. **82**, 703 (1951).
[3] W. D. Whitehead and S. C. Snowdon, Phys. Rev. **92**, 114 (1953).

W5. Total Cross Section of O_2 for Cold Neutrons.* R. M. EISBERG, H. PALEVSKY, M. E. RICKEY, AND T. I. TAYLOR, *Brookhaven National Laboratory.*—The total cross section of O_2 for neutrons has been measured in the neutron wavelength range 5A to 10A. A beam of cold neutrons from the Brookhaven pile was "chopped" into a series of bursts by a rotating cadmium shutter. The neutron time of flight over a 5 meter path between the shutter and a BF_3 filled proportional counter was recorded in a 12 channel analyzer. A 3.5 meter long target vessel was placed in the beam in good geometry with respect to the detector and the beam attenuation due to filling the target with 10 atmospheres of purified O_2 was measured. Backgrounds were measured by inserting a 0.010-in. cadmium foil in the beam. The temperature and pressure of the O_2 were measured to ¼ percent and the molecular density was computed from the Beattie-Bridgeman equation of state. The standard deviation of the cross section due to counting statistics were generally less than 1 percent. Corrections were made for the finite resolution of the time of flight analyzer. The measured cross section falls on a smooth curve passing through the following points: 14.5 barns at 5.00A, 19.6 barns at 7.71A, 23.4 barns at 10.00A.

* Work carried out under contract with U. S. Atomic Energy Commission.

W6. Magnetic Scattering of Cold Neutrons by Gaseous Oxygen.* H. PALEVSKY AND R. M. EISBERG, *Brookhaven National Laboratory.*—The scattering of neutrons by gaseous oxygen arises from the nuclear and magnetic interactions. The magnetic scattering is incoherent and does not interfere with the nuclear scattering;[1] therefore the total neutron cross section of the oxygen molecule is simply the sum of the magnetic and nuclear cross sections. In the wavelength region of interest the nuclear cross section can be accurately calculated[2] using the known free atom cross section of oxygen.[3] The experiment was performed by measuring the total neutron cross section for gaseous oxygen as described in the previous abstract. For the energy region investigated it is expected that the magnetic scattering is very nearly all elastic and therefore the wavelength variation of the magnetic scattering depends only on the spatial distribution of the magnetic moment in the oxygen molecule. For unity form factor the calculated magnetic cross section is 4.53 barns.[2] Subtracting the nuclear cross section from the measured cross section gives a smooth curve passing through 2.2 barns at 5A, 3.36 at 7.7A, and 3.8

at 10A. The shape of this curve indicates that the scattering is mostly elastic.

* Work carried out under contract with the U. S. Atomic Energy Commission.
[1] O. Halpern and M. H. Johnson, Phys. Rev. **55**, 898 (1939).
[2] O. Halpern and J. Appleton, Phys. Rev. **90**, 869 (1953).
[3] Harvey, Hughes, and Goldberg, Phys. Rev. **87**, 220 (1953).

W7. Neutron Moderation in SiO_2. JAY TITTMAN, *Schlumberger Well Surveying Corporation.*—The spatial distribution of In resonance neutrons about a point Ra-Be source has been measured in an essentially infinite silica medium under conditions similar to those previously reported.[1] The moderator consisted of a cubical pit 8 ft on an edge filled with 99.8 percent pure silica sand of density 1.61 ± 0.02 g/cm³. A thin-walled Al tube allowed insertion of the source and Al sheaths running through the moderator provided slots for foil positioning. Standard foil counting technique was used to establish the resonance 54-min saturation activity, including corrections for 4.5-hr activity induced by inelastic scattering and 54-min activity induced by kilovolt region neutrons.[2] Edge effects were shown to be negligible over the region studied. The data are fit by a simple Gaussian slowing down density for $2000 < r^2 < 10\,000$ cm², corresponding to an effective age $\tau = 1900 \pm 90$ cm². The second-order solution to the transport equation[3] then provides agreement with the experimental results down to $r^2 = 0$ and out to $r^2 = 17\,000$.

[1] J. Tittman and F. F. Johnson, Phys. Rev. **91**, 452 (1953).
[2] Roberts, Hill, and McCammon, Phys. Rev. **80**, 6 (1950).
[3] R. E. Marshak, Revs. Modern Phys. **19**, 213 (1947).

W8. Slowing-Down of Neutrons in Hydrogenous Moderators. P. F. ZWEIFEL AND H. HURWITZ, JR., *Knolls Atomic Power Laboratory.**—The age-diffusion approximation to the Boltzmann equation is inaccurate for neutrons slowing down in hydrogenous moderators because of the large neutron energy loss per neutron-proton collision. A program is under way to compare more elaborate calculational methods for a sinusoidal variation of neutron flux with position. Such a distribution is pertinent to reactor calculations and to the Fourier analysis of the neutron distribution from a point source. The methods include the spherical harmonic method[1] and an improvement on this method in which the system of equations is made finite by neglecting higher harmonics in the hydrogen scattering function rather than in the neutron flux.[2] A simpler but less accurate method in which the nonisotropic component of the hydrogen scattering is assumed not to change the neutron energy[3] has been included in the comparison. Numerical results for the Fourier transform of the slowing-down density from a point source of fission neutrons in water are presented, and results for the second spatial moment are compared.

* Operated for the U. S. Atomic Energy Commission by the General Electric Company.
[1] R. E. Marshak, Revs. Modern Phys. **19**, 200 (1947); G. C. Wick, Z. Physik **121**, 702 (1943); these methods may be shown to be equivalent.
[2] Bethe, Tonks, and Hurwitz, Phys. Rev. **80**, 11 (1950); G. C. Wick, Phys. Rev. **75**, 738 (1949); D. Selengut (private communication).
[3] This method, as applied to reactor calculations, has been suggested by D. Selengut and G. Goertzel.

W9. Standards for Thermal Neutron Capture Measurements. G. R. RINGO AND S. WEXLER, *Argonne National Laboratory.*—Comparison of the capture cross section of boron measured at Argonne with that measured at Brookhaven, Harwell, and Stockholm has shown excellent agreement with the Brookhaven results but not with the other two. Evidence of pronounced isotopic abundance variation was looked for and not found. There was also no evidence of disagreement in chemical analysis. The burden of the discrepancies which were several times the probable errors of the measurements is thus thrown on the physical measurements. Since the Argonne and Brookhaven results agree so well and are between the other two values, it is likely that the average of the Argonne and Brookhaven values, 752 barns for 2200 m/sec neutrons, is reliable to 1 percent. Although isotopic abundance ratios of boron have been reported to vary as much as 4 percent, none was found more than 1 percent from the Argonne standard in this study.

W10. Migration Areas of Po−Be Neutrons in H_2O−Zr Mixtures. W. BAER, *Westinghouse Electric Corporation.*—The spatial distribution of Po−Be neutrons moderated by water and zirconium has been measured for four water-zirconium volume ratios. Neutrons are detected by a $\frac{1}{4}$ in. diameter × 1 in. long enriched BF_3 counter, and data are taken with the counter bare and cadmium covered. Using the second and fourth moments of the spatial distribution, the mean square slowing down lengths below the cadmium cutoff are determined experimentally. From these results, the migration areas M^2 are evaluated. For pure water $M^2 = 66.3$ cm²; and for Zr/H_2O ratios of 0.25, 0.50, and 1.00, $M^2 = 77.5$, 87.2, 107.9 cm², respectively. The energy spectrum of the source has been determined experimentally, and a calculation made of the value of M^2 for the pure water case using the Marshak formula.[1] This calculation assumes only elastic scattering, and that the oxygen scattering is isotropic in the laboratory system. The theoretical value of M^2 is found to be 60.9 cm² for pure water. This value is 10 percent lower than the experimental measurement of M^2, and is presumed to be largely due to the anisotropy in the forward direction of neutron scattering from oxygen.[2]

[1] R. E. Marshak, Revs. Modern Phys. **19**, 209 (1947).
[2] Baldinger, Huber, and Procter, Helv. Phys. Acta **25**, 142 (1952).

SATURDAY AFTERNOON AT 1:30

Shoreham, Main Ballroom

(R. W. THOMPSON presiding)

Strange Particles of the Cosmic Rays

Invited Paper

X1. Positrons from Decay of Mu Mesons. RYOKUCHI SAGANE, *University of California, Berkeley.* (30 min.)

Contributed Papers

X2. Observations on Unstable Particles in Photographic Emulsion.* M. F. KAPLON, J. CRUSSARD, J. KLARMANN, AND J. NOON, *University of Rochester.*—Further evidence is presented for the existence of the alternate decay mode of the τ^+ meson.[1] A particle with a mass value of $1060 \pm 100\ m_e$, originating from a star classified as either $2+1_0$ or $2+0_p$, is observed

to decay into a π^+ meson of 15.2 Mev energy. Two cases of the normal 3 charged π decay of the τ meson are observed, one of which gives a precise Q value of 73.85 ± 1 Mev; it is noted that the τ meson mass is identical within experimental errors to that of the θ^0 meson.[2] A K meson is observed to be produced from a star with a total visible prong energy of 850 Mev; this may suggest a low production threshold. Another K meson is observed to suffer large angle inelastic scattering at low energy ($\sim$40 Mev) implying a direct nuclear interaction of this particle. Q values for 2 prong stars consisting of π^- mesons and protons will be reported; among these is a value of 37.8 ± 0.6 Mev,[3] corresponding to a Λ_0 decay.

* This research was supported in part by the U. S. Air Force under a contract monitored by the Office of Scientific Research, Air Research and Development Command.
[1] J. Crussard *et al.*, Phys. Rev. **93**, 253 (1954).
[2] The latest value reported by Thompson for the θ^0 at the Fourth Annual Rochester Conference was $965\pm10m_e$.
[3] In excellent agreement with a value of 37.7 ± 0.5 Mev reported by P. Fowler at the Fourth Annual Rochester Conference.

X3. Decay of a Heavy Neutral Particle. R. A. HOWARD, P. M. FITZPATRICK, H. E. HOFFMAN, AND J. S. URBAN, *University of Oklahoma.*—A V-shaped track has been found in a 400 micron Ilford G-5 emulsion exposed* to cosmic rays at 99 000 feet. The vertex of the V is 949 microns from a star of 19 prongs and is approximately coplanar with the star center. One branch of the V represents a particle which comes to rest in the emulsion after a distance of 962 microns. The other branch of the V has a smaller grain density and passes out of the emulsion without noticeable scattering after traveling 466 microns. Preliminary measurements indicate that the particle which came to rest had a mass at least equal to that of a proton, while the other particle was a meson. If one interprets this event as the emission from the star center of a neutral particle which subsequently decays into a proton and a meson then the Q is much lower than that of a Λ^0 decay. Careful remeasurements are underway to determine the masses and momenta of the decay particles with as high precision as is possible.

* Plates flown through courtesy of the General Mills Company and the U. S. Office of Naval Research.

X4. Charged Heavy Mesons from Nuclear Collisions. L. VOYVODIC, *National Research Council, Canada.*—Unstable heavy charged particles have occasionally been observed to arise from nuclear disintegrations in the energy region of several Bev. Two examples of such events are described, observed in 1000 micron Ilford G5 emulsions exposed in stratosphere balloon flights. After production in a star of type $1+21n$, a K particle of 8-mm residual range in emulsion decays at rest, yielding a secondary particle of 1.5 times plateau ionization. The rest mass obtained from range, ionization, and scttering on this probable kappa meson is 950 ± 150 m_e. In the second event an H particle, with mass 2100 ± 300 m_e, is produced in a star of type $0+9_p$. After traversing 12-mm emulsion the particle decays in flight near the end of its range, giving a secondary track at, or very near, plateau ionization.

X5. Magnetic Cloud Chamber Observation of *V*-Particles. I. Charged *V*-Particles.* Y. B. KIM, J. R. BURWELL, H. O. COHN, C. J. KARZMARK, AND R. W. THOMPSON, *Indiana University.*—The large magnetic chamber[1] (illuminated volume 22 in. high, 11 in. wide, and 5 in. deep situated in uniform field of 7000 gauss) has now been in operation for about 460 days at sea level with penetrating shower trigger requiring two or more particles below the chamber. Stereoscopic photographs of about 3000 penetrating showers (visible multiplicity of at least 3) have been obtained among which are found 146 examples of neutral V events and 63 examples of angular deflection without visible recoil. The nature of these deflections will be discussed; preliminary classification indicating that 29 of the 63 are decays of charged V particles (10 positive; 19 negative). The data is in the process of analysis and the results will be reported. In one example, R-423, the charged secondary is identified to be a negative pion (by $\pi-\mu$ decay) with a transverse momentum of 101 Mev/c.

* Assisted by the U. S. Office of Ordnance Research and by grant of the Frederick Gardner Cottrell Fund of the Research Corporation.
[1] Thompson, Buskirk, Etter, Karzmark, and Rediker, Phys. Rev. **90**, 329 (1953).

X6. Magnetic Cloud Chamber Observations of *V*-Particles. II. Status of Work on the θ^0 Meson.* R. W. THOMPSON, J. R. BURWELL, H. O. COHN, R. W. HUGGETT, AND C. J. KARZMARK, *Indiana University.*—Twenty-two neutral V events, exclusive of Λ^0 decay, have now been analyzed. The Q-curve plot of the data suggests in a natural way that twenty cases are examples of decay of the θ^0 (formerly called $V_4^{0\,1}$)$\rightarrow\pi^\pm+(\pi^\mp$ or $\mu^\mp)$, and thus confirm earlier evidence[1] for this particle and decay scheme. Within the limited statistics, the decay is isotropic in the C.M. system. With $m_\pi=139.7$ Mev, no revision of our earlier $Q(\pi,\pi)$ value of 214 ± 5 Mev is yet required, $M(\pi,\pi)=966\pm10$ m_e. There are two anomalous cases, 328[1] and R-439, which may indicate an alternate decay mode of the θ^0 (for example, $\theta^0\equiv\tau^0\rightarrow\pi^\pm+\pi^\mp+\pi^0$; or $\theta^0\rightarrow\pi+\mu+\nu$) or the decay of some new type of heavy neutral particle. These two cases would, of course, be explained if the main θ^0 decay mode were a 3-body process, but in view of the fit of the 20 "normal" cases, this appears to be an unlikely possibility unless the energy spectrum of the neutral particle in that 3-body process is very markedly different from the spectrum expected from statistical considerations.

* Assisted by the U. S. Office of Ordnance Research and by grant of the Frederick Gardner Cottrell Fund of the Research Corporation.
[1] Thompson, Buskirk, Etter, Karzmark, and Rediker, Phys. Rev. **90**, 1122 (1953).

X7. Production of V^0 Particles in Copper.* D. R. HARRIS AND A. L. HODSON, *Princeton University.*—A cloud chamber containing a $1\frac{1}{2}$ inch thick centrally located copper plate has been operated in a magnetic field at mountain altitude (10 800 feet).[1] The chamber was expanded following a coincidence corresponding to three or more minimum ionizing particles passing through each of three proportional counter trays. Two of these trays were below the cloud chamber and one was immediately under the central copper plate in the cloud chamber. 28 V^0 particles were observed to originate in interactions in the copper plate and to decay in the cloud chamber. Events in which these V^0's were produced have been analyzed as to the nature of the producing particles and compared to events in which V^0's were not observed. An analysis is shown for the calculation of momentum from a conical projection of a particle's track in a uniform magnetic field with transverse components.

* Supported by the U. S. Office of Naval Research and the U. S. Atomic Energy Commission.
[1] J. Ballam *et al.*, Phys. Rev. **91**, 1019–1020 (1953).

X8. Momentum of *S*-Particle Secondaries.* D. WILLARD, *M.I.T.*—We have made a statistical analysis of the scattering angles in lead plates of the charged secondary particles from eighteen S particles observed in the M.I.T. multiplate cloud chamber. Under the assumption that all secondaries have the same momentum, we found that the most likely value[1] of the momentum is 249 ($1\pm0.05\pm0.07$) Mev/c if all secondaries are mu mesons; 264 ($1\pm0.05\pm0.07$) Mev/c if all secondaries are pi mesons. 0.05 is the standard error (relative) arising from experimental errors. 0.07 is the standard error (relative) arising from the statistical nature of the theory. We shall present the method of analysis and discuss the manner in which our results can be interpreted.

* Research supported in part by the joint program of the U. S. Office of Naval Research and the U. S. Atomic Energy Commission.
[1] S. Olbert, Phys. Rev. **87**, 319 (1952); Annis, Bridge, and Olbert, Phys. Rev. **89**, 1216 (1953); Bridge, Peyrou, Rossi, and Safford, Phys. Rev. **90**, 921 (1953).

X9. Recent Results on *S* Particles.* H. S. BRIDGE, H. COURANT, B. DAYTON, H. C. DESTAEBLER, JR., B. ROSSI, AND D. WILLARD, *M.I.T.*—This paper presents a summary of recent results on charged heavy mesons which have been observed to stop and decay in the M.I.T. multiplate cloud chamber. The data include information on the ranges of the charged decay products and on the frequency and angular distribution of the associated photons.

* Research supported in part by the joint program of the U. S. Office of Naval Research and the U. S. Atomic Energy Commission.

X10. An Unusual Cosmic-Ray Event.* H. C. DESTAEBLER, JR., H. S. BRIDGE, H. COURANT, AND B. ROSSI, *M.I.T.*—We have observed a most unusual cosmic-ray event in the M.I.T. multiplate cloud chamber. A slow, heavy particle stops in one of the brass plates and produces 3 electron cascades. There is no other visible product. The showers diverge at wide angles and appear to be initiated by photons. Lower limits for the energies of the 3 showers are about 20, 130, and 590 Mev. More likely values are 160, 220, and 925 Mev. One might perhaps explain this event in terms of known particles, by assuming that the stopped particle is a negative heavy meson which undergoes nuclear absorption, thus transforming practically all of its energy into gamma rays. However, the masses of known heavy mesons do not appear to be quite sufficient to account for the observed energy release. If the event is a decay process, the conservation of momentum requires that a fourth unseen particle was emitted. In this case the lower limit for the total energy release is about 1200 Mev. The large value of the energy release raises the question as to whether the event may be interpreted in terms of an annihilation process.

* Research supported in part by the joint program of the U. S. Office of Naval Research and the U. S. Atomic Energy Commission.

SATURDAY AFTERNOON AT 1:30

Shoreham, West Ballroom

(JOHN MARSHALL presiding)

Nucleonic Scattering

Y1. Proton-Proton Cross Section at 95 Mev.* U. E. KRUSE† AND J. M. TEEM,‡ *Harvard University*.—The differential cross section for scattering of protons by hydrogen has been measured using the external proton beam of the Harvard cyclotron. Coincidences between the two protons scattered from targets of polyethylene and polystyrene were measured with suitable subtraction for the contribution from carbon. The number of incident protons was measured by means of a Faraday cup. The beam energy was determined by measuring the range in aluminum. The angular distribution from 90° to 40° in the center-of-mass system as determined in this way was found to be 4.6 mg/sterad at 90° and showed a slight rise toward small angles. Further checks are being planned using liquid hydrogen targets.

* Supported by the joint program of the U. S. Office of Naval Research and the U. S. Atomic Energy Commission.
† Society of Fellows.
‡ National Science Foundation Predoctoral Fellow.

Y2. Proton-Proton Scattering Near the Interference Minimum.* ROBERT L. ZIMMERMAN, DAVID H. FRISCH, AND DANIEL I. COOPER,† *M.I.T.*—The differential proton-proton scattering cross section at 45° in the laboratory system has been remeasured in the energy region from 350 to 420 kev. To calibrate the machine energy the alpha particles from the 340-kev $F^{19}(p,\gamma\alpha)$ reaction were observed in the same geometry and with the same proportional counters used in the proton scattering experiment. To do this a trace of fluorine-containing gas was mixed with the hydrogen in the scattering chamber. High current densities were obtained with the aid of an electro static alternating gradient lens above the scattering chamber. The interference minimum in the ratio to the Mott cross section was found to occur at 382.7 ± 1.5 kev, giving an *S*-wave phase shift at this energy of $\delta_0=0.2529\pm0.0011$ radians in agreement with our preliminary measurements.[1] The combination of our observation with the Wisconsin data[2] alone seems to exclude a static potential with a repulsive core. Such a conclusion agrees with an analysis by Yovits *et al.*[3] of data from a wide range of energies.

* Supported by the joint program of the U. S. Office of Naval Research and the U. S. Atomic Energy Commission.
† Now at Bell Telephone Laboratories.
[1] Cooper, Frisch, and Zimmerman, Phys. Rev. **90**, 339 (1953).
[2] Yovits, Smith, Hull, Bengston, and Breit, Phys. Rev. **85**, 540 (1952) survey and interpret all the data and quote the unpublished results of a thorough investigation by Heydenburg and Little in the low-energy region.
[3] Worthington, McGruer, and Findley, Phys. Rev. **90**, 899 (1953).

Y3. $p-p$ Scattering in Nuclear Emulsions.* S. K. KAO AND A. F. CLARK, *Carnegie Institute of Technology*.—A flux of two million protons per cm^2 with an energy of 420 ± 20 Mev passed through Ilford G-5 nuclear plates. The 200 micron thick emulsions are area-scanned for elastic p-p collisions which are identified by (a) an estimate of the corresponding grain densities along the tracks, (b) coplanarity of the tracks, (c) the proper angles. If we limit the azimuthal angles to less than 45°, the measurements on coplanarity angles are accurate to between 1 to 2°, and that of the angle between the scattered and recoiled protons to between ½ to 1°. The azimuthal angle is the angle between the plane of the plate and the plane of the event. Measurements of events and computations indicate that, with this angular resolution, quasielastic events will constitute only a small fraction of the elastic events. These background events are due to interaction with protons bound in a heavy nucleus. Forty-one acceptable events have been identified. Scanning is continuing to build up statistics.

* Supported in part by the U. S. Atomic Energy Commission.

Y4. The External Proton Beam of the Carnegie Synchrocyclotron.* J. A. KANE, R. A. STALLWOOD, R. B. SUTTON, T. H. FIELDS, AND J. G. FOX, *Carnegie Institute of Technology*.—A few percent of the internal proton beam of the synchrocyclotron emerges from the machine without benefit of a deflector or a scatterer. It emerges uniformly in azimuth with an energy of about 450 Mev. After passing through a

collimator 30 ft from the machine, its intensity is about 2×10^6/cm²/sec. Here the energy is 437 Mev due to degradation in the window and air. The beam is monitored with an ionization chamber similar to that of Chamberlain *et al.*[1] The contamination is about 5 percent of the total flux, and consists of a lower energy "tail" of protons which is essentially zero below 370 Mev. Three separate methods have been used to study this contamination (a) measurement of the angle between scattered protons in p-p elastic scattering; (b) measurement of the angular distribution of Cerenkov radiation from the beam traversing glass;[2] (c) a differential range technique using a coincidence-anticoincidence counter telescope. Scattering measurements indicate no left-right asymmetry, and thus the beam is presumed to be unpolarized.

*Work supported in part by the U. S. Atomic Energy Commission.
[1] Chamberlain, Segrè, and Wiegand, Phys. Rev. **83**, 923 (1951).
[2] R. L. Mather, Phys. Rev. **84**, 181 (1951).

Y5. Proton-Proton Scattering at 437 Mev.* R. B. Sutton, T. H. Fields, J. G. Fox, J. A. Kane, W. E. Mott, and R. A. Stallwood, *Carnegie Institute of Technology.*—Proton-proton scattering data, previously reported,[1] obtained by detecting the scattered and recoil protons in coincidence, using targets of CH_2 and C, were carefully checked and satisfactory agreement obtained. Additional data were taken with a liquid hydrogen target by two methods; in one the scattered and recoil protons were detected in coincidence as before for 90° and 50°; in the other only the higher-energy proton was detected using a two-counter coincidence telescope. At small angles enough copper was placed between the counters to absorb everything except elastically scattered protons. The detection efficiency of this telescope was measured in the direct beam with appropriate absorbers to reduce its energy. The relative values of the cross sections are as follows (the errors are from counting statistics):

C.M. angle	90°	65.3°	50.5°	36.4°	30°	27.8°	25.2°	16.6°
CH_2 target	1.00	1.03±0.03		1.16±0.03	1.16±0.03		1.24±0.03	
H_2	1.00		1.09±0.03			1.17±0.05		1.19±0.06

* Supported in part by the U. S. Atomic Energy Commission.
[1] Mott, Sutton, Fox, and Kane, Phys. Rev. **90**, 712 (1953).

Y6. The Total $p-p$ Cross Section Above 400 Mev. A. M. Shapiro, C. P. Leavitt, and F. F. Chen, *Brookhaven National Laboratory.*—The $p-p$ total cross section at six energies between 0.4 and 1.3 Bev has been measured in a program to study the energy variation of this cross section up to 3 Bev. A polyethylene-carbon difference method was employed in conjunction with a fast-coincidence counter telescope and magnetic analysis of the 32° scattered proton beam from a Be target in a Cosmotron straight section. The meson contamination was less than 1 percent. The momentum resolution was about ±4 percent. Transmission measurements were made with various values of θ, the half-angle subtended by the rear counter at the center of the absorber, from 1.9° to 8.3°. The cross sections at each energy were plotted against θ^2, and each total cross section was found by straight-line extrapolation to 0°. The preliminary cross sections are given below.

E (Mev):	410	535	615	830	1075	1275
σ_t (mb):	27	32	38	49	49	47

These values have been corrected for multiple Coulomb scattering in the absorber. The error in each of these points is approximately 2 mb. The sharp rise in the cross section from 400 to 800 Mev may be associated with an increase in the inelastic (meson production) cross section.

Y7. Pickup Deuterons Produced from 95-Mev Protons. W. Selove, *Harvard University.**—Deuterons produced by the interaction of the external beam of the Harvard cyclotron were detected in a scintillation-counter range telescope. Deuterons were separated from other charged particles by simultaneous measurement of range and specific ionization, and the energy distribution measured for deuterons above about 50 Mev, with a resolution of a few percent. Results will be reported of measurements which have been made at several angles with beryllium and carbon, and at one angle with aluminum, silicon, copper, and lead. Calculations are being made as to the nucleon distributions which can be inferred from the experimental results.

* On leave to Radiation Laboratory, University of California, Livermore California.

Y8. A Search for Polarization in Charge Exchange Scattering.* H. Bradner and R. E. Donaldson, *University of California, Berkeley.*—A refinement of Wouters'[1] experiment is being made to investigate the asymmetry produced by polarization in double exchange scattering of protons on C or Ta targets. Neutrons are produced in the first scatterer by the internal proton beam of the 184-inch cyclotron. These neutrons are converted in the second scatterer outside the shielding and recorded by two coincidence telescopes. The two telescopes are positioned by an unpolarized beam and all subsequent angular changes are made with the first scatterer. The results to date are:

Targets	1st angle	Counter angle ±6°	Bombarding energy Mev	Rejection energy Mev	$C=\frac{R-L}{R+L}$ percent
Ta	17°	25°	190	90	−1.4±1.6
C	17°	25°	190	110	0.5±2.9
C	35°	35°	245	90	5.2±3.0

Quoted errors are statistical probable errors plus an estimated one percent systematic error. An investigation is now being made on a 10°, 330-Mev initial scattering and on a single charge exchange scattering with a known polarized beam.[2]

* Supported by the U. S. Atomic Energy Commission.
[1] L. F. Wouters, Phys. Rev. **84**, 1069 (1951).
[2] Chamberlain, Segre, Tripp, Wiegand, and Ypsilantis, Phys. Rev. (to be published).

Y9. Polarization of 170-Mev Neutrons.* A. Roberts, J. Tinlot, and E. M. Hafner, *University of Rochester.*—A beam of 240-Mev protons strikes an internal target, T_1, and a set of neutron collimators is placed at the angle $\theta_1=29°$ (lab). Neutrons scatter from a radiator, T_2, and recoil protons are observed in a triple telescope at the angle θ_2 in a horizontal plane, to the left or right of the neutron axis. The telescope has a small acceptance angle (~2°) determined by brass slits, and is accurately mounted on a selsyn-driven turntable whose angular position can be read to 1′. The telescope contains an absorber whose thickness is varied with angle in such a way as to set a neutron threshold of 120 Mev at all angles. An additional internal target, producing forward neutrons on the same axis, is used to check the symmetry. Preliminary measurements have been made at angles $\theta_2=12$, 20, 30, 45, and 55 degrees, using T_1-T_2 combinations Be−CH_2, Be−C, C−CH_2, and C−C. We find that the Be−H asymmetry goes through a maximum of about 5 percent at 30°, and through zero near 45°. The Be−C asymmetry behaves differently, remaining positive up to 55°.

* Supported by the U. S. Atomic Energy Commission.

Y10. Polarization of 310-Mev Protons by Deuterium.* D. Nagle, J. Marshall, L. Marshall, and W. Skolnik, *The University of Chicago.*—The polarization of deuterium for 310-Mev protons has been examined as a function of angle in a preliminary measurement. Protons in an equilibrium

cyclotron orbit of 322-Mev average energy were polarized by scattering at 14° from an internal beryllium target. A scattered beam of 314-Mev protons emerging through the heavy shield were found to be 60 percent polarized as estimated from the asymmetry of a second scattering at 14° from beryllium in the experimental area. The asymmetry of scattering of this beam from liquid deuterium was examined from 8° to 36° aboratory angle, from which data the polarization of deuterium for this range of angles was estimated. The present results, from a single cyclotron run, seem to show a rather different behavior for deuterium than for hydrogen.[1] The polarization of deuterium shows little tendency to decrease with increasing angle, and in particular remains large at 90° in the baricentral system of the nucleon-scattered proton.

* Research supported by a joint program of the U. S. Office of Naval Research and the U. S. Atomic Energy Commission.
[1] Chamberlain, Segre, Tripp, Wiegand, and Ypsilantis; Marshall, Marshall, and de Carvalho, Phys. Rev. (to be published).

Y11. Elastic Proton-Deuteron Scattering at 95 Mev.* J. M. TEEM† AND U. E. KRUSE,‡ *Harvard University.*—The differential cross section for the elastic scattering of 95-Mev protons by deuterons has been measured at eighteen angles between 60° and 172° (center-of-mass) to a statistical accuracy of 3–5 percent. For scattering angles larger than 115° the elastic events were observed by identifying the recoil deuteron, using a telescope of counters which simultaneously measured its range and specific ionization. A CD_2-C subtraction was employed, but over most of the angular range the carbon contribution was reduced by requiring a coincidence between the scattered proton and the deuteron in the range-specific ionization telescope. For the smaller angles a range analysis of the protons in coincidence with particles at the recoil deuteron angle made possible an unambiguous separation of elastic and inelastic events. The absolute cross section was determined by the Faraday cup method. Comparison will be made with previous experiments on the scattering of neutrons and protons by deuterons.

* Supported by the joint program of the U. S. Office of Naval Research and the U. S. Atomic Energy Commission.
† National Science Foundation Predoctoral Fellow.
‡ Society of Fellows.

Y12. Neutron-Proton Scattering at 91 Mev.* R. H. STAHL, *Harvard University.*—The differential cross section for the scattering of neutrons by protons has been measured suing an external neutron beam from the Harvard cyclotron with an effective energy of 91 Mev. The proton target was a 3-cm diameter cylinder of liquid hydrogen in a 0.0006 in. Be−Cu foil container. Recoil protons were counted with good angular resolution in a scintillation telescope between 59° and 176° in the center-of-mass system. A similar telescope fixed at 140° with CH_2 radiator served as a beam monitor sensitive to variations in the neutron beam. Special attention was given to large angle scattering, and to the apparent asymmetry of scattering about 90°.

* Supported by a joint program of the U. S. Atomic Energy Commission and the U. S. Office of Naval Research.

Y13. Nuclear Internal Momentum Distributions.* J. M. WILCOX AND B. J. MOYER, *University of California, Berkeley.*—The nuclear internal momentum distributions of protons in light nuclei have been studied with the 340-Mev scattered proton beam from the synchrocyclotron. The two protons from a quasielastic scattering event are detected in coincidence, and the energy of one of them is magnetically analysed. In the limit of the impulse approximation, conservation of energy and momentum can be employed to solve for the momentum of the struck proton. The best fit to the experimental data for beryllium was obtained with a Gaussian momentum density distribution with a $1/e$ value of about 20 Mev. Fermi (rectangular) and Chew-Goldberger distributions did not fit as well. Qualitative differences were observed between lithium, beryllium, and boron.

* This work was done under the auspices of the U. S. Atomic Energy Commission.

Y14. Scattering of 10 Mev Protons on Magnesium and Carbon.* G. E. FISCHER, *University of California, Berkeley.*—In order to study the mechanism of excitation of nuclear levels by inelastic scattering, a scattering chamber of 36 in. diameter was constructed. The deflected beam of the Berkeley 60-in. cyclotron was brought out of the shielding by means of strong focusing magnets. Particles from the nuclear reactions were detected by either of two systems, a quadruple proportional counter telescope, or a coincidence crystal spectrometer. Energy resolution was of the order of 2.5 percent. The angular distribution of protons from the reactions $C^{13}(p,p^1)C^{13*}$ $Q=-4.47$ and $Mg^{24}(p,p^1)Mg^{24*}$ $Q=-1.38$ was found to be peaked in the forward direction. The elastic scattering of protons on the above nuclei were also studied and interference minima found. Two new levels are believed to have been found in Mg^{24}. Work on Si^{28} and Be^9 is in progress.

* This work was done under the auspices of the U. S. Atomic Energy Commission.

Y15. Proton Bremsstrahlung and High-Energy Gamma Emission from Carbon. DAVID COHEN, BURTON J. MOYER, HARLAN SHAW, AND CHARLES WADDELL, *University of California, Berkeley.*—A 180° pair spectrometer, similar to that here employed previously in π^0 experiments, capable of spectrum analysis in the range 10–150 Mev, has been employed in a study of the bremsstrahlung from bombardment of nuclei by high-energy protons below threshold for π^0 production. The bremsstrahlung is apparently appropriate to the $(E/2-h\nu)^{\frac{1}{2}}(d\nu/\nu)$, modified by nucleon momentum distributions, which is expected from electric dipole radiation in $N-P$ collisions. Superimposed upon the bremsstrahlung in the case of carbon nuclei is a strong line emission at 15.2 ± 0.2 Mev. This line emission is present over a variation in proton bombarding energy from 30–340 Mev; and it is also produced by deuteron bombardment of B^{11}, but not of B^{10}. It is believed to belong to a C^{12} nuclear transition for which disintegration into three alphas is forbidden by either parity or isotopic spin selection rules.

Y16. Elastic Scattering of Alpha Particles by Heavy Nuclei.* GEORGE W. FARWELL AND HARVEY E. WEGNER,† *University of Washington.*—The elastic scattering of alpha particles by Ag, Ta, Pb, and Th has been studied at energies of 13 to 42 Mev. Variation of cross section with energy at a scattering angle of 60° is similar to that previously reported for Au.[1] At low energies, the cross section for each material follows the Coulomb dependence. At higher energies, the cross section falls rapidly as the alpha-particle energy increases, following the empirical formula $\sigma(E)=\sigma(E_0)\exp[-K(E-E_0)]$. The critical energy E_0 increases with Z. The coefficient K is about 0.26 Mev^{-1} and is nearly the same for all elements studied. Interpretation of results in terms of a semiclassical strong absorption model due to Blair[2] leads to values of the sum of nuclear radius and alpha radius in agreement with the empirical formula $D=(1.50A^{\frac{1}{3}}+1.5)10^{-13}$ cm.

* Partially supported by the U. S. Atomic Energy Commission.
† Now at Brookhaven National Laboratory.
[1] George W. Farwell and Harvey E. Wegner, Phys. Rev. (to be published).
[2] J. S. Blair, abstract following.

SATURDAY AFTERNOON AT 1:30

NBS, East Building

(S. MILLMAN presiding)

Solid-State Physics, III, Mostly Metals

Invited Paper

Z1. Noise in Semiconductors, Rectifiers, and Transistors. R. L. PETRITZ, *Naval Ordnance Laboratory.* (30 min.)

Contributed Papers

Z2. Electronic Quadrupole-Quadrupole Interactions in Cerium Metal.* J. M. KELLER AND E. KOENIGSBERG,† *Iowa State College.*—Electronic multipoles arise from the charge density of electrons in incomplete atomic shells. Interactions between multipoles about different atoms are principally quadrupole-quadrupole (Q-Q). For rare earth metals, the Q-Q interactions of the $4f$ shell electrons are of the same order of magnitude as the crystal field (charge-multipole) interactions. The Q-Q contributions to the electronic energy and specific heat at temperatures below 20°K cannot be neglected. We have investigated these contributions for hexagonal cerium, treating the conduction electrons as a uniform negative charge distribution. Measured values of specific heat[1] cannot be reproduced by a theory including crystal fields but ignoring Q-Q interactions. Nor is the disagreement removed by including Q-Q effects, but assuming different electronic states distributed at random among the lattice sites. It is probable that the specific heat anomalies are associated with breakdown of some type of ordering. Including Q-Q interactions, ordered arrangements of electrons in the crystals have been found, with energies considerably lower than for random electron arrangement. In all the ordered arrangements studied, electrons of two different orientations are located in alternating crystal planes.

* Work supported by the U. S. Atomic Energy Commission.
† Now at Midwest Research Institute.
[1] Parkinson, Simon, and Spedding, Proc. Roy. Soc. (London) **A207**, 137 (1951).

Z3. Axial Ratios in Hexagonal Metals. J. W. MCCLURE,* *University of Chicago.*—A theoretical study has been made of the deviations of the axial ratios of hexagonal metal crystals from the ideal close-packing value. The procedure followed was to express the shearing stress in the close-packed configuration as an expectation value, using a method similar to that of Fuchs and Peng.[1] This yielded a generalized virial theorem. Introducing the Hartree-Fock approximation and making use of commutation relations allowed us to express the stress as a sum of three terms: (1) an integral taken over the surface of an atomic polyhedron, which can be interpreted as a "kinetic stress" due to the electrons; (2) a lattice sum of electrostatic interactions, which is quite small; and (3) an exchange contribution. In the weak potential case (1) reduces to the estimates of Jones[2] and Goodenough,[3] while in the more general case it has the same qualitative behavior. A rough estimate of (3) showed that it was appreciable and thus should be taken into account.

* National Science Foundation Predoctoral Fellow.
[1] K. Fuchs and H. W. Peng, Proc. Roy. Soc. (London) **A180**, 451 (1942).
[2] H. Jones, Phil. Mag. **41**, 663 (1950).
[3] J. B. Goodenough, Phys. Rev. **89**, 282 (1953).

Z4. An Analysis of the Forbes Bar Method for Measuring the Thermal Conductivity of Metals.* JOSEPH M. CLIFFORD AND R. B. SAWYER, *Lehigh University.*—Hogan and Sawyer[1] calculated the conductivity of a specimen from the results of two experiments: a measurement of the power required to maintain the specimen at a uniform temperature above that of the surrounding furnace, and a measurement of the temperature along the specimen with one end heated. Newton's law of cooling was assumed in both experiments; the heat-transfer coefficient calculated from the first was used, in the second, to obtain the lateral heat loss from the specimen. However, since the heat-flow patterns in the insulation surrounding the specimen are different in the two experiments, the heat-transfer coefficient calculated from the first experiment is not strictly applicable to the second. Calculation of the temperature distribution within the specimen and the insulation during the second experiment leads to conductivities which, in some cases, are appreciably smaller than those previously reported. Revised conductivities will be shown for AISI stainless steel types 347 and 446.

* Supported by the Office of Ordnance Research, U. S. Army.
[1] C. L. Hogan and R. B. Sawyer, J. Appl. Phys. **21**, 177 (1952).

Z5. High-Speed Transient Dynamic Analysis.* JOHN C. LINDSAY† AND A. V. MASKET, *The University of North Carolina.*—The transient dynamic analyzer developed at Chapel Hill has been employed to measure the forces during the penetration of mild steel, aluminum, and a composite of steel and aluminum by ogival and cylindrical projectiles. Accuracy is generally better than 5 percent. Values of a real material deceleration as large as 10^6 g or greater are easily measured during the impact. Details of the method and typical results will be presented.

* Supported by the U. S. Office of Naval Research.
† Now with E. I. du Pont de Nemours and Company.

Z6. Volume Changes in Substitutional Alloys. A. W. ROSS AND D. TER HAAR,* *St. Andrews University, Scotland.*—The coefficient of volume expansion of a linear chain consisting of equal numbers of A and B atoms has been evaluated. The potential energies for AA, BB and AB pairs are assumed to be $v_{AA}=v_{BB}=A+B(r-r_1)^2$, $V_{AB}=C+B(r-r_2)^2$, where $r_2<r_1$, corresponding to the smallest volume for a completely ordered state, and where C is chosen such that the ordered state is the state present at absolute zero. It is found that dL/dT varies roughly as the specific heat. In the case of a simple cubic lattice the expansion coefficient shows a discontinuity at the Curie point.

* On leave of absence at Purdue University.

Z7. Small Angle X-Ray Scattering from Cold-Worked Al–Ag and Al–Zn Alloys.* J.-P. JAN AND J. S. KOEHLER, *University of Illinois.*—Alloys of high purity Al with 30 wt percent Ag were annealed in the one phase region, quenched and reduced to half the original thickness by cold rolling. Non cold-worked samples give a small angle scattering identi-

cal to the one observed by Walker and Guinier,[1] corresponding to spherical clusters of Ag atoms, with a radius of gyration of 10A. Cold-worked samples exhibit a strong anisotropy effect, corresponding to an elongation of the Ag clusters in the direction of rolling. The ratio of the radii of gyration parallel and perpendicular to the following direction is 1.4. Similar results were obtained from larger amounts of cold work and Al-30 wt percent Zn. The anisotropy increases with the amount of cold work. The growth of the clusters on aging in the first stage of precipitation is isotropic in a non cold-worked specimen. In a cold-worked specimen, the clusters became more isotropic on aging.

* Supported by the U. S. Atomic Energy Commission, the U. S. Office of Ordnance Research and the «Bourse Bonjour» of the University of Lausanne, Switzerland.

[1] C. B. Walker and A. Guinier, Acta Metallurgica 1, 568 (1953).

Z8. Resistivity of Ordered and Disordered Copper-Gold Alloys at Low Temperatures.* E. PASSAGLIA AND W. F. LOVE, *University of Pennsylvania.*—The resistivity of copper-gold alloys of composition 25, 37.5, 50, 62.5, and 75 atomic percent gold has been measured as a function of temperature from room temperature to 4.2°K in states slowly cooled and rapidly quenched from above the ordering temperatures for this system. The room temperature resistivities agree with those previously obtained by Johansson and Linde.[1] The residual resistances are high in both the quenched and slowly cooled states, but the ratio of the residual resistance to the ice point resistance was found to be appreciably lower in the slowly cooled states for the 25 percent and 50 percent compositions. The other compositions showed no such difference in the residual resistance ratio. The resistivity data was analyzed using the Gruneisen[2] function. Values of the Debye temperature calculated in this manner were found to be strongly temperature dependent, but no appreciable difference was found between quenched and slowly cooled states. Hysteresis anomalies of the order of 1 percent were found in the neighborhood of 225°K.

* Supported by the U. S. Atomic Energy Commission.

[1] C. H. Johansson and J. O. Linde, Ann. Physik **25**, 1 (1936).
[2] E. Gruneisen, Ann Physik. **16**, 530 (1933).

Z9. Electronic Energy of Ordered Alloys. EDWARD W. HART, *General Electric Research Laboratory.*—The change of electronic energy of an alloy for small departures from perfect ordering can be formulated as equivalent to an impurity problem. If the departure of the lattice potential from that for perfect long range order is considered as a perturbation on the perfect lattice, the energy change per misplaced atom can be estimated by first-order perturbation theory. The principal part of the energy shift of the band functions appears as a rigid band shift. For an idealized one-dimensional diatomic lattice of alternating atomic specie, the energy change per defect is positive for the lowest energy band and is negative for states in the next higher band. It should be emphasized that the stabilizing effect of the ordered state which may arise in this way is demonstrable only for departures from perfect order in the ordered phase and does not compute the relative energy of the disordered phase. It is unnecessary for the treatment reported here to assume an equivalent lattice of weighted means of atomic potentials although it can be shown by the present treatment that this assumption is a good first approximation in the ordered phase.

Z10. Lattice Distortion and X-Ray Diffraction Intensities in Dilute Solid Solutions.* WILLIAM J. TAYLOR, *Ohio State University.*—It is assumed that: (1) the solute atoms are randomly distributed in (substitutional or interstitial) sites $\mathbf{r}_\alpha$; (2) the mean ratio of solute atoms to sites is z; (3) a solute atom at $\mathbf{r}_\alpha$ displaces a lattice atom at $\mathbf{r}_j$ by an amount $\mathbf{u}_{j\alpha}$ depending only on $\mathbf{r}_j-\mathbf{r}_\alpha$; (4) the total displacement of the lattice atom at $\mathbf{r}_j$ is $\mathbf{u}_j=\Sigma_\alpha \mathbf{u}_{j\alpha}$ where the sum extends over all solute atoms. The Laue-Bragg diffraction by the lattice depends on the effective scattering power $f_j\langle\exp(i\mathbf{k}\cdot\mathbf{u}_j)\rangle_{Av}$, where f_j is the atomic scattering power (corrected for thermal vibration), $\mathbf{k}$ is the diffraction vector, and the angular brackets indicate an average over-all solute atom configurations. An application of the Markoffian theory of random processes yields the exact result $\langle\exp(i\mathbf{k}\cdot\mathbf{u}_j)\rangle_{Av}=\exp\{-z\Sigma_\alpha[1-\cos\times(\mathbf{k}\cdot\mathbf{u}_{j\alpha})]\}$, where the sum on the right extends over all solute atom sites. The sum converges, and the remainder for $|\mathbf{r}_j-\mathbf{r}_\alpha|$ greater than several interatomic distances can be approximated adequately as a Fresnel integral by inserting the elastic theory formula for a spherical strain, $\mathbf{u}_{j\alpha}=A(\mathbf{r}_j-\mathbf{r}_\alpha)/|\mathbf{r}_j-\mathbf{r}_\alpha|^3$, where A is determined by the lattice expansion. An experimental program has been initiated to determine whether inversion of this expression is capable of yielding the displacements for $|\mathbf{r}_j-\mathbf{r}_\alpha|$ too small for elastic theory to apply.

* Supported by the Aeronautical Research Laboratory, Wright Air Development Command.

Z11. A Neutron Diffraction Study of the Copper-Manganese System. DAVID MENEGHETTI AND S. S. SIDHU, *Argonne National Laboratory.*—A neutron diffraction study of a series of continuous solid solutions of manganese in copper up to 85 atomic percent manganese has been made. It shows that at compositions above 13 atomic percent manganese, a broad peak appears in the region of (100) reflection of the face-centered cubic lattice. A correlation of this peak with the magnetic attraction of the alloys indicates that it is at least in part due to short-range magnetic order. Its intensity decreases at compositions greater than about 50 atomic percent. At compositions greater than about 69 atomic percent manganese a sharp diffraction line occurs at the position of a (110) reflection of the face-centered cubic unit cell. This line is temperature dependent and vanishes at 380°K. It is proposed that this reflection arises from an antiferromagnetic coupling between manganese atoms as the manganese concentration becomes predominant. No long-range crystal ordering was observed in these samples. The neutron patterns of the furnace-cooled samples did not change by heat treatment of the alloys for a period of three days at 750°C and followed by quenching in water.

SATURDAY AFTERNOON AT 1:30

NBS, Materials and Testing

(R. T. BIRGE presiding)

Post-Deadline Papers, If Any

SUPPLEMENTARY PROGRAMME

SP1. Microtron Maximum Particle Energy.* H. F. KAISER, *Naval Research Laboratory.*—The maximum particle energy attainable by a microtron may be increased in several ways: (a) simple enlargement of the magnetic pole area with operation at a given energy gain per turn; (b) increase of gain per turn by higher powered resonators; (c) increase of operating frequency allowing use of higher magnetic resonant fields,[1] and (d) combination with other types of accelerating processes at possible expense of reduced net duty factor. The last mentioned may consist in (1) modification of the microtron to include a local guide field which may be time-modulated and superposed on the static field in the region of a final particle orbit with the object of trapping the charge in this orbit and accelerating it in synchronous fashion as the local field grows. (2) the microtrons final orbit may be caused to take a rectilinear path and be injected into a larger acceleration structure (conventional or strong-focusing accelerators). The problems involved in these two approaches will be examined and discussed.

* To be given at the end of Session C if the Chairman rules that time permits.

[1] H. F. Kaiser, Phys. Rev. **87**, 183 (1952); **91**, 456 (1953); J. Franklin Inst., February, 1954.

SP2. Nuclear Masses as Rational Multiples of the Electron Mass. ENOS E. WITMER, *University of Pennsylvania.**—The mass of any nucleus in any state may be represented by Mm, where m is the rest mass of the negative electron. M appears to be always an integral multiple of 2^{-n}, where n is a positive integer or zero. Furthermore it seems probable that $n \leq 8$ always. In any case the application of the latter idea to all the existing data has produced remarkable agreements and remarkable results. Thus the nuclear mass of O^{16} is found to be $29148(13/128)m$, which yields $m = 0.000548\ 770\ 2859$ amu by taking account of the binding energy of the electrons. Using this value of m on the nuclear masses recently published by Bainbridge yields the following M-values that are astoundingly close to integers.

Nucleus	M-value
Li^7	12786.00006 ± 0.0474
C^{11}	20065.9998 ± 0.0437
O^{16}	27340.0007 ± 0.0237
F^{17}	30983.0003 ± 0.0200

For $A \leq 17$ there are 25 nuclear masses with a probable error of $\pm_4 0.051m$ or less. The probability of this situation arising by chance is only 3×10^{-9}.

* To be given at the end of Session FA if the Chairman rules that time permits.

SP3. Suppression of Pair Effects in Nuclear Forces. ABRAHAM KLEIN,* *Harvard University.*†—One can think of the fourth-order nuclear potential (exchange of two mesons) as the virtual scattering of a meson by each nucleon. The adiabatic limit can be viewed as the limit in which the nucleon transfers zero four-momentum during each interaction with the meson field. It follows that the fourth-order pair potential, including radiative corrections, is given exactly by the perturbation theory result if the "bare" coupling constant is replaced by the renormalized one defined by the meson-nucleon scattering experiment in the limit of zero kinetic energy and meson mass. This gives $g^2/4\pi = 0.36 - 2$, which may be interpreted as a suppression of pair production in the sense that the coupling constant required to account for the P-wave effects (and the S wave in photomeson production) is an order of magnitude larger. Higher-order pair potentials are not given simply by the perturbation result with the above value for the coupling constant. Though a considerable class of radiative corrections is thus included (finite), radiative corrections to multiple vertices, constituting an increasing class of corrections in higher order, are omitted. The effect of such terms can be estimated at present only by perturbation methods.

* Society of Fellows.

† To be given at the end of Session U if the Chairman rules that time permits.

Author Index to Papers Presented at the 1954 Washington Meeting

Ajzenberg, F., W. Franzen, and J. G. Likely—Q16
Alberger, D. E.—N1
Albert, R. D., M. L. Yeater, and E. R. Gaerttner—RA2
Allen, Lew, Jr., and A. O. Hanson—L6
Allen, Robert C.—P13
Ambler, E., R. P. Hudson, and G. M. Temmer—KA2
Andrews, David H.—OA2
Arnowitt, Richard and S. Gasiorowicz—IA2
Aschenbrenner, F. A.—C5
Atkinson, W. R., R. G. Fowler, and W. R. Holden—OA10
Austern, N. and S. T. Butler—DA6
Autler, S. H. and W. F. Roat—B16
Axel, P. and J. D. Fox—G13
Babiskin, J. and M. C. Steele—D3
Baer, W.—W10
Baldwin, G. C., F. R. Elder, and W. F. Westendorp—C8
Bandtel, Kenneth C., Wilson J. Frank, Richard Madey, and Burton J. Moyer—Q4
Bartholomew, G. A., F. Brown, H. E. Gove, A. E. Litherland, and E. B. Paul—SA6
Bartnoff, Shepard—H11
Bashkin, Stanley—Q7
Baumann, N. P., F. W. Prosser, Jr., and R. W. Krone—SA8
Beams, J. W. and J. B. Breazeale—D2
Bedo, D. E. and D. H. Tomboulian—JA3
Beeman, W. W. and R. H. Neynaber—I7
Belinfante, F. J. and J. C. Swihart—M2
Bell, R. E.—SA14
Bennett, A.—F13
Bent, R. D., R. W. Bonner, and R. F. Sippel—SA5
Bergmann, Peter G.—M4
Berlincourt, Ted G. and M. C. Steele—D10
Bernstein, J. and A. Klein—U10
Bernstein, W., J. Weiss, and J. B. H. Kuper—FA2
Bersohn, R.—H5
Beidenharn, L. C., R. L. Gluckstern, and M. H. Hull, Jr.—V5
Birman, Joseph—I11
Birnbaum, G. and A. A. Maryott—JA10
Birnbaum, W., W. E. Crandall, G. Millburn, and R. V. Pyle—SA3
Blair, J. S.—DA4
Blaser, J., J. Ashkin, F. Feiner, J. Gorman, and M. O. Stern—K4
Block, M. M. and D. T. King—S14
Bludman, Sidney A.—U8
Boag, J. and B. Zendle—FA1
Bollinger, L. M., R. R. Palmer, and D. A. Dahlberg—RA10
Bolsterli, M. and E. Feenberg—G3
Borowitz, Sidney—V2
Bortner, T. E. and G. S. Hurst—FA6
Braams, C. M.—SA11
Braden, C. H., E. T. Patronis, Jr., and L. D. Wyly—KA12
Bradner, H. and R. E. Donaldson—V8
Bray, P. J.—F2
Bridge, H. S., H. Courant, B. Dayton, H. C. DeStaebler, Jr., B. Rossi, and D. Willard—X9
Brode, Harold L.—VA5
Brolley, J. E., Jr., W. C. Dickinson, and R. L. Henkel—SA16
Brown, Fielding and Charles L. Gravel—T6
Brown, H. A. and J. M. Luttinger—T7
Brown, H. N., F. B. Smith, and R. A. Becker—KA6
Broyles, A. A.—V7
Brueckner, K., C. Levinson, and H. Mahmoud—U11
Buechner, W. W., C. P. Browne, H. Enge, M. Mazari, and C. D. Buntschuh—FA3
Bunker, M. E., J. W. Starner, and J. P. Mize—G10
Burgess, James H.—F10
Burson, S. B., W. C. Jordan, and J. M. LeBlanc—G11
Burkhardt, J. L. and E. J. Winhold—L9
Callaway, Joseph—V3
Caren, R. P. and C. E. Nielsen—C14
Carlson, R. R. and E. B. Nelson—Q12
Carroll, Thomas J.—JA16
Carter, R. S. and J. A. Harvey—RA6
Champion, K. S. W. and S. C. Brown—OA9
Chinowsky, William and Jack Steinberger—K1
Church, E. L. and M. Goldhaber—KA5
Clement, J. R.—D1
Clifford, Joseph M. and R. B. Sawyer—Z4
Codrington, R. S., J. D. Olds, and H. C. Torrey—F8
Coester, F.—M6
Cohen, B. L., G. H. McCormick, T. H. Handley, and E. Newman—Q1
Cohen, David, Burton J. Moyer, Harlan Shaw, and Charles Waddell—Y15
Cohen, Marshall H.—V13
Collins, T. L., T. T. Scolman, and A. O. Nier—H7
Collinson, J. A. and W. W. Watson—JA6
Cook, C. F., T. W. Bonner, and J. B. Marion—Q2
Crandall, W. E., W. Birnbaum, and L. Schecter—IA12
Cross, W. G. and T. A. Eastwood—KA16
Crussard, J., W. D. Walker, and M. Koshiba—K6
Cunnell, F. A. and E. E. Schneider—B12
Cutkosky, R. E.—U2
Daggett, E. H. and G. R. Grove—KA14
Dahlberg, D. A. and L. M. Bollinger—RA9
Davis, Charles F., Jr., and M. W. P. Strandberg—F6
Davis, L., Jr., G. A. deMars, L. G. Rubin, and W. D. Straub—B6
Dawson, J. M. and Z. I. Slawsky—H3
deBoisblanc, D. R. and K. A. McCollom—FA5
Dempsey, E. and D. ter Haar—T2
der Mateosian, E.—RA11
DeStaebler, H. C., Jr., H. S. Bridge, H. Courant, and B. Rossi—X10
Dettman, J. W. and A. Schild—M8
Dexter, R. N., H. J. Zeiger, Benjamin Lax, and E. S. Rosenblum—B8
Drachman, R. J. and D. C. Peaslee—DA7
Draper, J. E. and C. P. Baker—RA4
Dresden, M.—D11
Drisko, R. M.—FA15
Dropkin, J. J. and S. Orgel—B9
Edwards, D. A., B. Wolfe, A. Silverman, and J. W. DeWire—L10
Efremov, N.—H1
Eggler, C. and C. M. Huddleston—C10
Eisberg, R. M., H. Palevsky, M. E. Rickey, and T. I. Taylor—W5
Eisenberg, Y.—S8
Eisinger, J., C. F. Cook, and C. M. Class—L3
Engel, Olive G.—H10
Fafarman, A. and M. H. Shamos—S12
Falkoff, D. L.—F4
Fang, P. H.—M9
Farwell, George W. and Harvey E. Wegner—Y16
Ferguson, G. A., J. Halpern, R. Nathans, and P. F. Yergin—W3
Fields, T. H., J. G. Fox, J. A. Kane, R. A. Stallwood, and R. B. Sutton—PA6
Finlay-Freundlich, E.—U7
Fischer, G. E.—Y14
Fischer, Vera Kistiakowsky—KA3
Fisher, L. H.—J4
Fluharty, R. G.—FA4
Foner, Simon—T3
Fowler, Charles A., Jr., and Edward M. Fryer—T4
Frenkiel, F. N.—VA1
Frisch, Harry L. and Joel L. Lebowitz—QA8
Gaffney, John and W. C. Overton, Jr.—D4
Garber, M. and D. E. Mapother—D13
Gardner, J. and J. Bunbury—M5
Geiger, K. W. and D. C. Rose—RA12
Geller, K., J. Halpern, and Paul F. Yergin—W4
Gibbons, J. H. and H. W. Newson—RA1
Gibson, G. and P. Stehle—V12
Givin, H. H., G. K. Farney, T. M. Hahn, and B. D. Kern—Q15
Goldberger, M. L., M. L. Gellman, and W. E. Thirring—U5
Goldburg, W. I., S. A. Cox, and R. M. Williamson—L4
Golden, Robert K. and Sherman Frankel—G16
Gourary, B. S. and R. W. Hart—T8
Gove, H. E., E. B. Paul, A. E. Litherland, and G. A. Bartholomew—SA9
Green, C. D. and D. ter Haar—QA7
Green, D. W., J. N. Cooper, and J. C. Harris—FA9
Greenberg, J. Mayo—IA7
Greenblatt, M. H.—OA4
Griffith, Gordon L.—P4
Guernsey, Janet B. and Clark Goodman—P7
Gupta, Suraj N.—M1
Guss, Donald, Lawrence Killion, and F. T. Porter—KA9
Gutowsky, H. S.—A2
Haar, Lester and A. S. Friedman—H4
Hafner, Everett Mark—DA3
Handley, T. H. and B. L. Cohen—G2
Hanson, H. P. and J. R. Knight—JA1

Hanson, W. B. and J. R. Pellam—D15
Harman, T. C., R. K. Willardson, and A. C. Beer—B3
Harris, D. R. and A. L. Hodson—X7
Hart, Edward W.—Z9
Harvey, J. A., C. E. Porter, and D. J. Hughes—RA8
Heckrotte, Warren—IA10
Heinz, O.—FA8
Henkel, John H.—I4
Henry, Warren E.—D9
Herman, R. C., I. L. Mador, R. F. Wallis, and M. C. Williams—B10
Hesketh, R. V. and E. E. Schneider—B13
Heydenburg, N. P. and G. M. Temmer—L5
Holmes, John R. and Leon Pape—JA5
Hopson, J. E. and C. E. Nielsen—C13
Horton, G. K. and E. Phibbs—DA1
Hourd, R. F., J. R. Fleming, and J. J. Lord—S5
Howard, R. A., P. M. Fitzpatrick, H. E. Hoffman, and J. S. Urban—X3
Hudis, J., E. Baker, and G. Friedlander—G4
Hudson, R. P.—O5
Hughes, Raymond H.—JA7
Hunt, W. A., R. M. Kline, and D. J. Zaffarano—G1
Hurley, J. P. and P. S. Jastram—KA8
Jackson, J. David—SA15
Jackson, J. L. QA2
Jacobs, Donald H. and Milton E. Pugh—H14
Jacobsohn, B. A.—U6
Jakobson, M. and J. H. Manley—C7
Jan, J.-P. and J. S. Koehler—Z7
Jancovici, B.—IA8
Jansen, L. and Z. I. Slawsky—H2
Jennings, B., J. B. Weddell, and R. L. Hellens—P3
Johnson, C. H. and J. L. Fowler—P12
Johnson, F. S., J. D. Purcell, and R. Tousey—JA4
Johnson, Peter D. and Ferd E. Williams—B15
Johnston, L. H., E. A. Day, and J. H. Williams—C1
Jones, D. R.—K9
Jones, Harry—F1
Kaiser, H. F.—C6, N2, SP1
Kane, J. A., R. A. Stallwood, R. B. Sutton, T. H. Fields, and J. G. Fox—Y4
Kao, S. K. and A. F. Clark—V3
Kaplon, M. F., J. Crussard, J. Klarmann, and J. Noon—X2
Karle, I. L.—O2
Keller, J. M. and E. Koenigsberg—Z2
Kiehn, Robert M. and Clark Goodman—P6
Kim, Y. B., J. R. Burwell, H. O. Cohn, C. J. Karzmark, and R. W. Thompson—X5
King, D. T. and H. M. Block—S13
Klein, Abraham—U9, SP3
Klein, Martin J. and Paul H. E. Meijer—QA4
Koehler, W. C. and E. O. Wollan—T9
Koerts, L., A. Schwarzschild, R. Gold, and C. S. Wu—G7
Koshiba, M. and M. F. Kaplon—S10
Koslov, S., V. Fitch, and J. Rainwater—K12
Krohn, V. and S. Raboy—F12
Kruse, U. E. and J. M. Teem—Y1
Kunz, W. E., C. D. Moak, and W. M. Good—Q8
Lafferty, D. L., L. A. Rayburn, and T. M. Hahn—P9
Landsberg, P. T.—QA10
LaPorte, Otto—VA2
Lassettre, E. N., A. S. Berman, S. Silverman, and M. E. Krasnow—OA12
——, S. Silverman, and M. E. Krasnow—OA13
Lax, Benjamin, H. J. Zeiger, and R. N. Dexter—B7
Lax, Melvin and Joel L. Lebowitz—I5
Lazar, N. H. and P. R. Bell—G8
LeBlanc, J. M., J. M. Cork, and S. B. Burson—KA11
Leder, Lewis B. and L. Marton—OA7
Lehner, J. and G. M. Wing—QA3
Leiss, J. E. and C. S. Robinson—PA3
Levin, J. S. and D. J. Hughes—RA5
Levine, S. H., R. S. Bender, J. N. McGruer, and W. F. Vogelsang—Q6
Levinson, C., K. Brueckner, and H. Mahmoud—U12
Levinson, John—T1
Levinthal, Cyrus—E3
Lindenbaum, S. J. and Luke C. L. Yuan—PA8
Lindqvist, Torsten and Allan C. G. Mitchell—G9
Lindsay, John C. and A. V. Masket—Z5
Linsley, John—S6
Loeb, A. L. and J. B. Goodenough—I2
Loeb, L. B.—J3
Lokanathan, S., J. Steinberger, and H. B. Wolfe—K8
Lorrain, Paul, R. Béique, P. Gilmore, P. E. Girard, A. Breton, and P. Piché—C4
Lyons, D. H. and A. M. Feingold—DA12
Lyons, Harold—O1
Malenka, B. J.—IA13
Malkus, Willem V. R.—VA4
Malm, R. and D. R. Inglis—Q14
Mandeville, C. E. and H. O. Albrecht—B14
Mann, D. E. and Earle K. Plyler—JA8
Mann, Leonard A., Ray A. Grandey, and Arnold F. Clark—S11
Marder, S., V. W. Hughes, and C. S. Wu—FA16
Mark, Hans, Clyde McClelland, and Clark Goodman—L2
Marshall, J. F., R. A. Shatas, and M. A. Pomerantz—OA6
Marshall, John—R2
Marton, L.—J1
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Matthias, B. T.—O4
McClure, J. W.—Z3
McCormick, Philip T.—V11
McGuire, A. D., M. Camac, M. L. Halbert, and J. B. Platt—K10
McSkimin, H. J., A. J. Williams, and R. M. Bozorth—I3
Melvin, M. Avramy—H9
Meneghetti, David and S. S. Sidhu—Z11
Merritt, J. and D. Hamlin—PA5
Metzger, F. R. and W. B. Todd—KA13
Mihelich, J. W.—KA7
Millburn, G. P., W. Birnbaum, W. E. Crandall, and L. Schecter—IA11
Miller, D. W., V. K. Rasmussen, and M. B. Sampson—SA4
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Miskel, J. A. and M. L. Perlman—G6
Mize, J. P., J. W. Starner, and M. E. Bunker—KA10
Moak, C. D., W. M. Good, and W. E. Kunz—Q11
Morrison, P.—S3
Moszkowski, Steven A.—DA2
Mould, R. E. and D. E. Mapother—D14
Muehlhause, C. O., E. der Mateosian, and Michael McKeown—B11
Muschlitz, E. E., Jr.—OA14
Nagle, D., J. Marshall, L. Marshall, and W. Skolnik—Y10
Neaves, A. and D. ter Haar—B1
Neiler, J. H., F. Muckenthaler, and James Schenck—Q5
Nelkin, M. S. and H. A. Bethe—IA3
Nelson, E. B., E. H. Geer, and R. R. Carlson—SA7
Newkirk, J. B.—I1
Newson, H. W. and J. H. Gibbons—Q10
Nielsen, C. E. and J. E. Hopson—C15
Noon, J. H. and M. F. Kaplon—S7
Noyes, H. P.—IA5
O'Neill, Gerard K.—P2
Orear, Jay, C. H. Tsao, J. J. Lord, and A. B. Weaver—K7
Osborne, L. S., Y. Goldschmidt-Clermont, and G. Parker—PA1
Overton, W. C., Jr. and J. R. Clement—D5
Packard, M. E.—A3
Palevsky, H. and R. M. Eisberg—W6
Palma, M. B., M. U. Palma, and D. Palumbo—F9
Park, David—T5
Parratt, L. G.—I6
Passaglia, E. and W. F. Love—Z8
Peaslee, D. C.—DA8
Peck, R. A., Jr.—C3
Penfold, A. S. and J. E. Leiss—PA2
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Reynolds, J. B. and K. G. Standing—Q3
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Roberts, A., J. Tinlot, and E. M. Hafner—Y9
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Rogers, F. T.—VA6
Rogers, T. F.—JA9
Rohrlich, F.—V10
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Rosenstock, Herbert B.—I10
Rosenthal, Jenny E.—OA1
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Ross, Marc H.—IA4
Rothstein, Jerome—QA11
Ruark, Arthur E.—M13
Rubin, Robert J.—QA1, QA9
Rushworth, F. A.—F11
Sagane, Ryokuchi—X1
Sampson, John L., Edward E. Altshuler, and Charles R. Mingins—I9
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Saraf, Babulal—G5
Schaeffer, Oliver A. and Henry R. Owen—H8
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Segall, Benjamin—DA11
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Selove, W.—Y7
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Shapiro, A. M., C. P. Leavitt, and F. F. Chen—Y6
Shapiro, I. I. and J. M. Teem—IA9
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Simpson, O. D.—C11
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Stearns, M. B., M. Stearns, L. Leipuner, and S. DeBenedetti—K11
Stahl, R. H.—Y12
Steenberg, N. R.—DA10
Steffen, Rolf M.—G17
Stein, Irving—M14
Steinberger, Jack and William Chinowsky—K2
Stern, A. W.—M11
Sternglass, E. J.—FA7
Sternheimer, R. M.—V1
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Swann, W. F. G.—S2
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Tamor, S.—IA14
Taylor, William J.—Z10
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Teller, Edward—N3
Temmer, G. M.—L1
ter Haar, D.—D16, O3
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Tinlot, John—R3
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Trammell, G. T.—IA6
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Urquhart, H. M. A. and J. E. Goldman—T10
Varma, Jagdish—G14
Vasileff, H. D.—I12
Voyvodic, L.—X4
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Wada, W.—IA1
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Waniek, R. W. and Vaughn Culler—W2
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Watanabe, Satosi—M10
Weigand, Clyde—R1
Weinstock, E. V. and J. Halpern—L11
Welton, T. A.—M12
Wick, G. C.—U1
Wilcox, J. M. and B. J. Moyer—Y13
Willard, D.—X8
Willardson, R. K., T. C. Harman, and A. C. Beer—B4
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Witmer, Enos E.—FA13, SP2
Wood, R. E.—RA3
Wolfenstein, Lincoln—R4
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Yamaguchi, Yoriko and Yoshio Yamaguchi—U4
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Yevick, George J. and Jerome K. Percus—QA5
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